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ABSTRACT

A simulation system capable of supporting human factors experiments in the development of military training devices is described. The first phase of the study consisted of (1) a review of tasks performed by the operators of different types of military simulation systems, (2) an analysis of problems experienced in the development of devices for such training tasks, and (3) the identification of design areas in which experimentation is required. The second phase of the project resulted in the formulation of design recommendations and a five-year implementation plan to permit system procurement in five relatively discrete incremental modules. Each of the five modules can be employed independently, and each can also be integrated with the preceding module to provide additional, supplemental functions. Procurement of all five modules will provide for the total capability necessary for the support of future human factor experiments in military training. (Author/DGC)

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Technical Report: NAVTRADEVCEN 69-C-0207-1

STUDY TO DETERMINE THE REQUIREMENTS FOR AN EXPERIMENTAL TRAINING SIMULATION SYSTEM

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ORLANDO, FLORIDA 32813

Technical Report: NAVTRADEVCEN 69-C-0207-1

STUDY TO DETERMINE THE REQUIREMENTS FOR AN EXPERIMENTAL TRAINING SIMULATION SYSTEM

ABSTRACT

The purpose of this study was to design a simulation system capable of supporting human factors experiments in the development of training device designs. The study was performed in two phases. The first phase consisted of a review of tasks performed by the operators of four general types of military systems, an analysis of problems experienced in the development of devices for training these tasks and the identification of design areas in which experimentation is required. Five design areas were identified, including: (1) design of the trainee station for training specific tasks and under particular circumstances, (2) the effects of various levels of system fidelity on training, (3) determining requirements for representation of the environment outside the operator's (trainee's) station, (4) development of techniques for automated training, and (5) development of effective instructor station designs. The second study phase produced system design recommendations and a five-year implementation plan, to permit system procurement in five relatively discrete incremental modules. Each of the five modules can be employed independently, and each can also be integrated with the preceding procurement to provide additional, integrated functions. Procurement and integration of all five modules will provide a total capability consistent with the overall purpose of the study.

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FOREWORD

This study had as one of its objectives the specification of requirements for a generalized simulation system in which the important functional characteristics of training systems can be simulated and analyzed. A review was made of various major training devices to identify operational areas requiring research. Another objective was the planning and design of the equipment, housing facilities, and personnel staffing.

The Experimental Training-Simulation System (ETSS) will provide the capability to assemble, in building block fashion, various types of simulators such as procedural, part task, whole task, etc. Each module will be designed to provide a distinct experimental capability. Additional capability will result from the combined utilization of two or more modules. Conceivably, some experimentation will utilize all modules as a complex system. A modular design concept is considered preferable to an array of various individual simulator designs. It will provide flexibility and enable the degree of simulation to be adjusted in manipulating a wide variety of training alternatives to a given problem. This feature will permit evaluation of the training effects of different kinds of individual and group practice on a single task in advance of specific trainer system development. Another advantage in the modular approach is that it results in less overall cost.

In keeping with the implementation plan, the ETSS would evolve over a period of approximately five years. Consequently, the staff and equipment can be acquired in increments, with the experience gained in the early years being used to modify the plan, if necessary.

Follow-on work will be directed at implementing the ETSS and conducting experimentation as permitted by the build up of the hardware configurations. A variety of disciplines including training psychologists, systems engineers, and computer personnel will participate in this developmental phase. The hardware and software will be tested as components and subsystems are completed. Tests of the total system will be conducted by the staff during the final phase of the development.

As an aid to the reader in following the development of the entire study, a foldout is provided on pages M-21/M-22 (Figure 44, ETSS Study Overview).

Joseph A. Puig
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Project Psychologist

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SECTION I

INTRODUCTION

A two-phase study was performed to identify areas of human factors experimentation required to develop effective training device design and use, and to explore and identify methods for implementing experimentation requirements. The study was performed in support of the Naval Training Device Center, Human Factors Laboratory, whose major function is to supply data and interpretations on the nature of tasks for which training is required, on the adequacy of the various potential approaches for meeting these needs, and on the nature of the psychological processes associated with the design, operation and evaluation of training equipment and systems.

Relevant data are available on which to base design of devices for training operational tasks and skills, however, specific design questions can be adequately answered only through the acquisition of new data, because of the uniqueness of the task or its operational context and/or because of new information in the area of training technology. In these cases, capabilities are essential for generating objective experimental information on which to base specific device and system design characteristics, and to prescribe methods of training device use.

Phase I of the study resulted in identification of five areas in which experimentation is needed in supplying human factors data and interpretations in the development of effective training device designs: 1) the design of the trainee station for training specific tasks and under particular circumstances; 2) needs for various levels of system fidelity; 3) determining requirements for representation of the environment outside the operator's (trainee's) station; 4) development of techniques and methods for automated training; and 5) development of effective instructor station designs for a variety of training devices.

Phase II explored various ways of implementing these five experiment requirements.

Initial attempts at developing discrete approaches for each of the five areas identified areas of high redundancy;

representation of displays at the operator's station normally employs the same equipment as does the synthesis of an experimental instructor's station; communications channels designed to permit tactical unit leaders to "war game" are also used in relaying instructions from a computer or an instructor to a subject in a computer-based instructional experiment. As a consequence of this overlap, experimental training simulation task components were selected, assembled and organized to support all of the required experiment functions.

The laboratory system described in this report is referred to as the Experimental Training Simulation System (ETSS).

SECTION II

STATEMENT OF THE PROBLEM

It was the purpose of this study to define the capabilities and requirements of a laboratory system capable of obtaining quantitative information for use in the development of training device design and utilization concepts, and to facilitate optimum device and system training effectiveness. The first step in fulfilling this function was to identify the problems requiring specific laboratory capabilities. The spectrum of training device design problems encountered by Naval Training Device Center ranges from infantry rifle trainers to automated complex vehicle trainers like the Synthetic Flight Training System (Device 2B24). In order to provide a simulation system capable of supporting experiments in all problem areas, the task elements of representative types of operational systems had to be defined. The major design goal of the Experimental Training-Simulation System (ETSS) was to allow experimentation in the greatest number of areas through flexible programming and hardware design.

A major requirement of the system design was for a general simulation capability in which the important functional characteristics of a wide variety of training devices could be identified, simulated and evaluated. As a corollary requirement, it was essential that the system facilitate evaluation of training strategies applicable to the systems operational use, and that it provide a test bed for development of techniques to be used in field evaluations of existing and potential training systems. A principal use of the resulting system will be to define characteristics and specification requirements for new training devices. Appendix B includes a matrix of the types of human factors design questions that might be raised to define a system such as Device 2F88, the F4J Weapon System Trainer. Device 2F88 was chosen for review because of its relative complexity in the inventory of training devices and systems and because, as such, it touches on an unusually wide range of perceptual, learning and simulation problems. The general device requirements expressed in the 2F88 MC were reviewed in light of potential research needs in training and training device design, and from experience in the development and execution of programs for training complex skills.

Additional requirements for the experimental evaluation of training methods, techniques, and device characteristics were identified through the analysis of less formally documented training requirements. It is clear from both formal and informal analyses that the specification of training devices deals with a large number of issues which, in the final analysis, dictate capabilities for experimentation. The ETSS was conceived as a generalized simulation system incorporating a variety of features never before incorporated in a single installation. It includes systems for the simulation of vehicular motion, out-of-the-window visual scenes and system dynamics, as well as capabilities for data storage and retrieval to be used both in support of specific experiments and in the more generalized literature research functions of the Human Factors Laboratory.

SECTION III

METHOD

The study was performed in two phases: 1) a review of operational military systems, system functions, and personnel tasks having significant training implications, and of the needed experiments arising from these implications; and 2) definition of a simulator system capable of solving problems in training design and utilization. Figure 1 (Page 6) graphically illustrates the two phases and the related sequence of tasks.

The first phase of the study reviewed operator tasks in four military operational areas: airborne systems, ocean surface systems, ocean subsurface systems, and land systems. During the first phase, five experimental areas having significant human factors research implications were identified:

1. The Trainee Station - Ordinarily the configuration of a training device should duplicate those parts of the operational work station relevant to the training being provided. Effective training frequently demands, however, that the work (or trainee) station of the device incorporate additional or modified characteristics. A part of the research capability under consideration should be capable of defining, evaluating, and specifying perceived discrepancies between the operational work station and the device trainee station, as they are required to promote effective learning. In some instances, for example, supplementary indicators of trainee performance may have to be added to the trainee station. In others, some work station equipment may have to be deleted to minimize task complexity during the early stages of learning.

2. Fidelity of System Dynamics - Closely related to the physical configuration of the trainee station is the manner in which the operating characteristics of the trainee station and the simulated operational system are represented to the trainee in the device. In some training systems it is possible, feasible and desirable for the controls and displays in the trainee station to operate and interact in exactly the same manner as in the corresponding operational system. In many instances, however, it is either not possible or feasible for the device dynamics to duplicate those of the prime system. In others, the progress of learning may be advanced through the introduction of discrepancies between device and

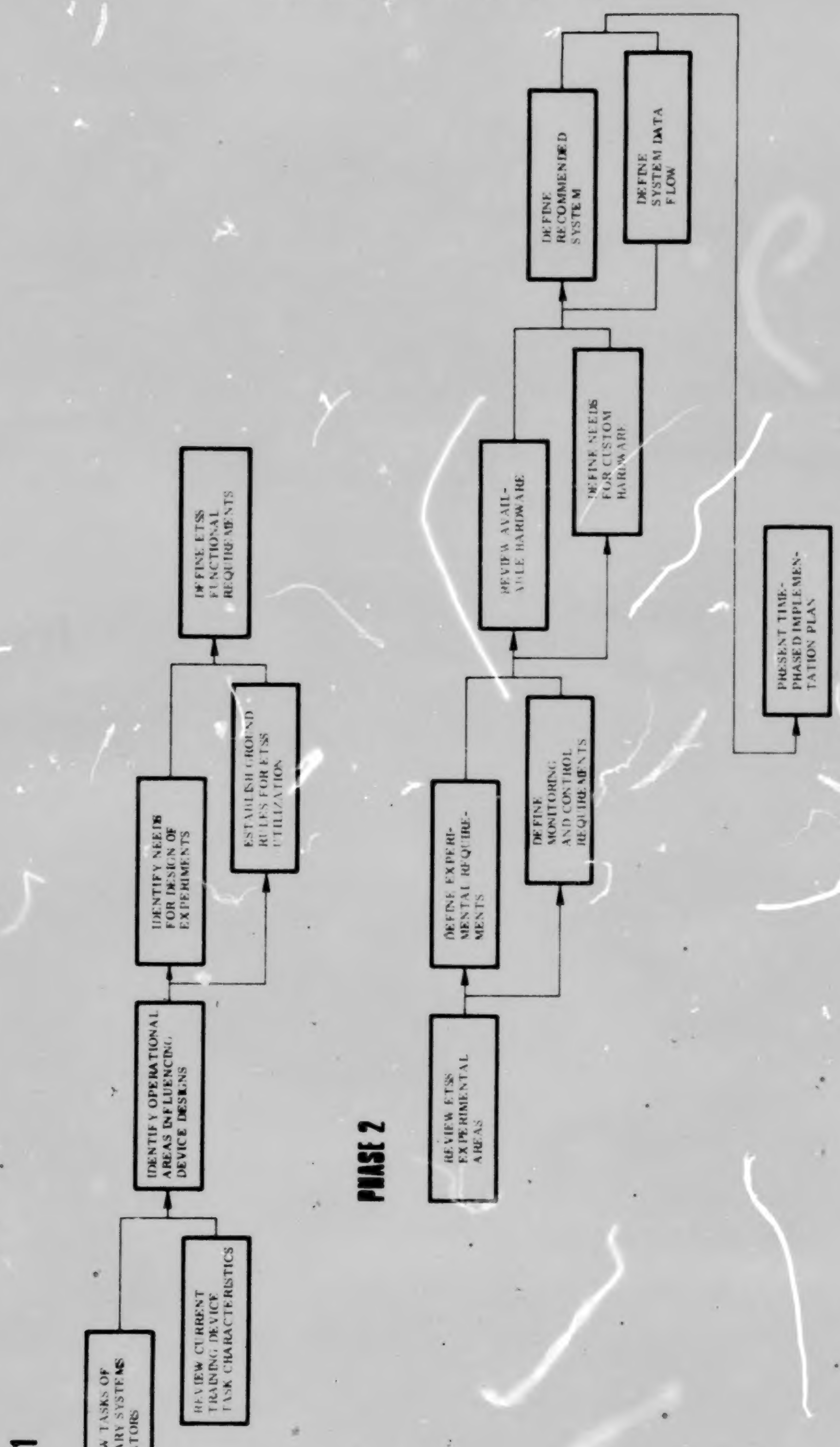
PHASE 1
REVIEW TASKS OF MILITARY SYSTEMS OPERATORS
REVIEW CURRENT TRAINING DEVICE TASK CHARACTERISTICS
IDENTIFY OPERATIONAL AREAS INFLUENCING DEVICE DESIGNS
IDENTIFY NEEDS FOR DESIGN OF EXPERIMENTS
ESTABLISH GROUND RULES FOR ETSS UTILIZATION
DEFINE ETSS FUNCTIONAL REQUIREMENTS
PHASE 2
REVIEW ETSS EXPERIMENTAL AREAS
DEFINE EXPERIMENTAL REQUIREMENTS
DEFINE MONITORING AND CONTROL REQUIREMENTS
REVIEW AVAILABLE HARDWARE
DEFINE NEEDS FOR CUSTOM HARDWARE
DEFINE RECOMMENDED SYSTEM
DEFINE SYSTEM DATA FLOW
PRESENT TIME-PHASED IMPLEMENTATION PLAN

Figure 1. Study Program Events

system dynamics, particularly in initial training. Thus, means are required for accomplishing research to develop methods of compensating for losses in fidelity due to problems in cost and/or technical capability, and to establish requirements, based on the nature of the learning process, for the modification of represented system dynamics, in assuring efficient learning.

3. External Environment Fidelity (Vision, Motion and Sound) - Sounds produced by the operation of system equipment, or which impinge on system personnel from **outside** the system, vehicle motions and real-world visual data are frequently significant in learning and in accomplishing specific system functions. In many instances, learning rate and effectiveness can be enhanced by the manipulation of these cues. It may be desirable to reduce or increase their distracting value, to emphasize certain cues during specific training phases, or to introduce cues which are not a part of the operational environment for which training is being provided, but which might help in the training process. Means are also required for establishing the environmental characteristics and utilization modes most appropriate to specific types of operator training. Environmental sounds and work **station** motion in particular can, in many systems, provide essential information, distractions, and stresses that can significantly influence performance and learning. Many motions are not feasible to reproduce in the training device, and indeed some need not be reproduced if they can be represented adequately for the task being trained in other ways, or if their absence can be compensated for through experience in the operational system. Trainee station motions and aural cues have varying significance, depending on the capabilities of the trainee and on the significance of sound or motion for the particular training task: they can be primary cues to performance; they may act as reinforcements for other cues; they may act only as distracting influences; or they may have little or no significance. As a result, another requirement exists for a laboratory capability for defining the degree of aural and motion simulation required for training specific skills to specific levels, for defining the most effective methods of compensating in training, for cues which cannot be adequately represented, and for relating modes of cue representation to trainee perceptual characteristics. Visual contact with the world in which the system operates also plays a large and significant role in the employment of many military systems. Vehicle control, particularly, requires detailed, accurate,

and timely response to relationships with objects on the surface over, under or upon which the vehicle operates, and with other vehicles operating in the same general environment. Tactical operations at almost all levels also involve the perception of spatial relationships among units, equipment, terrain features, and movements. As a result, training in vehicle operation and utilization and in the employment of weapons and tactical systems depends significantly on the exposure of the trainee to the visual environment. Safety, economy, training efficiency, and time severely limit the use of operational systems in operational settings for training. Simulation is employed to provide opportunities for trainees to develop essential perceptions and response capabilities, but the simulation of visual cues has in the past been deficient in accomplishing some required training functions. As a result, requirements exist for an experimental facility capable of specifying visual cue requirements for specific training tasks.

4. Instructional Management and Programming - Training devices are tools employed in the control of specific learning processes. They provide the stimuli and the response capabilities required in the development of essential knowledges and skills. They do not provide or ensure training per se, however, but may permit certain significant aspects of training to occur. Whether or not training does in fact occur, as well as the quality of training, depends on the aspects of the training system that organize and control the presentation of stimuli, and that measure, evaluate and guide trainee performance and learning. Many of these functions are traditionally performed by an instructor, and many always will be. Recent developments in training have allocated more and more control to instructional and computer programs, however, representing tendencies both to increase training objectivity and to make more effective use of the instructor, consistent with his particular capabilities. The motivation for, and to a large extent the result of, these tendencies has been more careful planning and programming of instruction and more efficient utilization of instructional personnel. Currently, however, comparatively little objective information is available to permit specification of the most effective methods of allocating and implementing instructional functions among the instructor, the computer, and the lesson plan. The ETSS will permit the objective evaluation of alternate modes of instructor/equipment utilization in the management of specific training situations.

5. Instructor Station Design - Training device effectiveness depends heavily on the quality of the interface between the instructor and the trainee. In the design of many training devices, experimentation is needed to define the best way of facilitating instructor monitoring, guidance, evaluation and control of the learning process. A basic function of the ETSS is to provide capabilities for experimentation in the selection, design, arrangement and utilization of instructor station components.

Throughout the study, particularly in the Phase I portion, consideration was given to the environment in which experimental evaluations will occur, to assure the design of a system that is not only relevant to the device design problems to be solved, but practical within the constraints of its employment. Three major influences are reflected in the design of the system and its equipment:

1. The Experimental Training-Simulation System will be employed directly by personnel in the Human Factors Laboratory. A minimum of additional support personnel will be required, but the system has been designed to be operated by personnel currently within the Laboratory. Computer terminals and programs and other equipment modules have been selected and designed to require a minimum of special training and ability.

2. The subjects available to the Laboratory for the evaluation of training device design alternatives tend to constrain the mode of utilization of the system. It is likely that the subject population will consist at least in part, of local college students and laboratory personnel having little or no special training or experience in the systems for which training devices are being developed. It is assumed that in the case of complex experiments reflecting major characteristics of the prime system, military personnel having relevant operational experience will be made available, but that the great majority of experiments will deal not with the operational characteristics of the prime system, but with the essential psychological, perceptual, and skill elements, which can, as required, be combined to permit evaluations of more complex, system-related tasks.

3. The total system recommended in this study, including the computer, interface, operator terminals and other associated display, processing, and control equipment, would cost less than $10 million. It is unlikely that the total system

could be procured at one time, either from the point of view of cost, or in terms of procurement lead time. As a result, all system components have been conceived, designed, and organized for modular procurement so that each item of equipment procured provides a distinct experimental capability. Additional capability will accrue both from the procurement of additional items and from the combined utilization of those available at a given time.

SECTION IV

RESULTS

1. PHASE I

The initial objective of Phase I was to identify the military operational areas that would significantly influence training device requirements of the future. A further goal was to identify specific areas in which human factors research will be required to optimize training device design. A review was made of the major NTDC training devices currently employed by the Navy, the Marine Corps and the Army, to identify operational areas that had significantly influenced design to date. An analysis of tasks prepared by Naval personnel was also reviewed. (1) Operator tasks associated with the areas reviewed were, in turn, reviewed for their training implications. Appendix A is a summary of tasks performed by operators of a variety of military systems, together with estimates of their training significance.

Discussions with personnel of the Human Factors Laboratory of the Naval Training Device Center verified the significance of these current operational areas with respect to future device requirements. Interviews with designers and users of training devices, and a review of the training research literature, identified areas requiring research in optimizing training device design and utilization. Table 15 (Page B-2) of Appendix B is a summary of human factors research areas identified in the literature review as relevant to the design and development of a wide variety of military training systems. These areas were a first indication of the range and variety of capabilities to be required of the Experimental Training-Simulation System. Table 16 (Page B-26) of Appendix B illustrates the results of a review of the specification for a typical complex training device, Device 2F88, the F4J Weapon System Trainer. A significant number of research areas identified in the literature review were associated with specific characteristics of the 2F88. This matrix of research areas was a second indication of the need for a human factors research capability in the development of specific training device designs. Further, more specific experimental needs resulted from more detailed reviews of the tasks involved in operating a variety of military systems, as discussed in the following sections.

1.1 TRAINING DEVICE REQUIREMENTS BY OPERATIONAL AREAS. Through reference to the Naval Training Device Center's Training Device Guide (2) and through interviews with NAVTRADEVCEN Human Factors Laboratory personnel regarding devices currently in the field and devices anticipated for future procurement, four military operational areas were identified: airborne systems, ocean surface systems, ocean subsurface systems and land systems. Space systems were excluded from consideration, primarily because of the relatively low level of NAVTRADEVCEN participation in the development and procurement of training devices for space application. All facets of system operation for the four classes of trainers were considered to identify all operator training areas having significant implications for training device development and design. Emphasis was placed on operator task responsibilities, as opposed to maintenance tasks, to limit the effort to training areas having most direct and immediate relevance to operational system effectiveness. It should be noted that while the study was oriented toward system operator personnel, the term "operator" includes not only the personnel who employ equipment, but also all personnel, units, and organizations who enable it to accomplish its operational military functions.

Throughout the review of military systems, the system mission, the tasks required of system operator personnel, and the nature and effects of the operating environment were assessed in order to anticipate training and training device requirements. At the same time, experience with typical training devices in each of the four was reviewed. The review facilitated the identification of classes of training device design and utilization problems requiring attention, particularly within the responsibility of the Human Factors Laboratory.

1.1.1 Airborne Systems. A large proportion of the money and time spent in the training of military personnel is spent in training crews of a wide variety of airborne systems. Aircrew responsibilities were reviewed in relation both to flight control tasks and to the tasks required in the operation of the various weapon, navigation, and sensor systems carried by military aircraft. Among the aircraft systems reviewed were fixed-wing and rotary-wing aircraft, fighters, interceptors and bombers, tactical support aircraft, anti-submarine and airborne early warning aircraft, cargo and tanker aircraft, and aircraft employed primarily in rescue operations.

1.1.2 Ocean Surface Systems. The study identified five general types of surface ships which have both common and unique personnel task and training implications. Surface ships include those designed for anti-aircraft, anti-submarine, and anti-ship missions. Assault ships and amphibious-assault vehicles were also considered within the surface ship category because of their common requirements for training in helm and engineering procedures and in maneuvering and docking.

1.1.3 Ocean Subsurface Systems. Several unique subsurface systems are currently in operation, and an even greater variety requiring specialized training will be in operation over an extended period of time (3, 4). The complexity of most subsurface systems, due to the variety of mission functions to be performed and the severity of the operating environment, imposes heavy and significant requirements for the training of system operating personnel. All subsurface systems require skill in the operation not only of systems directly related to the specific mission, but also of systems having significance primarily for the conditions imposed by the operational environment (5, 6). Attack submarines, missile submarines, and oceanographic systems have common problems in navigation, diving, surfacing, propulsion, maneuvering, and life support. Each type of system also has specific functional requirements in fulfilling its own unique mission responsibilities. Each, in turn, has requirements for personnel training and training devices, some of which are in common among all these types of systems and with some other military systems, some of which are unique to specific systems and missions. Oceanographic submarines, for example, must perform dead-reckoning navigation functions similar to those employed in attack and missile submarines, in aircraft, tanks and surface ships. They also have mission functions in underwater research (including SCUBA operations), collection of geological and biological samples, and underwater exploration, which are unique.

1.1.4 Land Systems. A wide variety of skills are required in the operation and employment of military systems confined primarily to the surface of the land. Many significant and critical training requirements are associated with the employment of wheeled, tracked, amphibious, and air cushion vehicles. Each vehicle requires training in normal and emergency operating procedures, maneuvering, navigation and tactical employment. Many contain weapon systems which also require training in operating procedures and tactical employment

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Many significant training requirements are also associated with artillery and infantry systems, aside from those related to the operation and employment of the various individual and crew-served weapons. Some of these also involve tactical operations. Training for these is a problem, since large expanses of terrain, many people and large quantities of equipment must be maintained if the training environment is to be realistic. The nature of combined land/tactical exercises lends itself, however, to synthetic training, since little direct contact with terrain, units and elements is required for effective training. The knowledge and skills involved in this area can be trained to a very large extent through emphasis on communications procedures and content (7).

1.2 TRAINING SYSTEMS AND RELATED TASKS. Phase I orientation was pointed at the identification of problems in the design of systems and devices used in the development of operator skills, which could be solved in the Experimental System under consideration. It was anticipated early in Phase I that some problems would relate to more than one type of operational system, and that a few would relate to only one or a very few tasks and systems, in terms of the perceptual, psychological, and learning processes involved. When the tasks and skills identified in the review of operational systems have been enumerated, 13 categories emerged, which represent relatively unique operations and operational settings. These 13 operator tasks in turn each consist of components of the five more or less classic training problem areas, knowledges, perceptions, procedures, perceptual motor skills and judgmental skills. Appendix A lists the major learning functions involved in each of these 13 operator or personnel task categories.

1.2.1 Ship Control. The size, weight, inertia, surface friction and speed of surface ships and submarines make control of their speed and direction a unique problem both for operations and training. Development of a device that is capable of training a number of diverse skills in one simultaneous, coordinated training exercise requires unique techniques in device design as well as in design of the means for ensuring effective communication and coordination. The basic skills involved in surface maneuvering include:

a. Individual and crew operating procedures to define, command, and achieve a desired course and speed.

b. Perception of relative bearing, track and velocity of own and other ships.

c. Appreciation of velocity, acceleration, control lag and turning characteristics of own and other ships in selecting and achieving specific courses and velocity.

d. Ability to predict and control relative bearing, course and position of own ship.

e. Communication procedures required to assure optimum crew interaction.

1.2.2 Submarine Operations. Submarine surface maneuvering is similar to maneuvering of conventional surface ships and also requires a minimum of specific attention in training research. The unique environment and functional capabilities of submarines, however, involve tasks and task contexts that require independent attention in the development of effective training, particularly in submerged operations. Maneuvering under the surface requires the coordinated efforts of a number of personnel. Submarine dynamics, speed, maneuverability and vulnerability to excessive hull pressures make specific training and experience mandatory for safe and efficient operation. Diving, hovering and surfacing also involve complex, critical skills and coordinations, particularly for:

a. Hatch control
b. Ballast and vent control
c. Control of diving planes and rudder
d. Perception of diving angle and diving rate; ability to lead depth with plane, ballast, and vent controls.
e. Appreciation of submarine diving, surfacing and hovering dynamics.
f. Crew communications procedures
g. Automatic hovering control procedures.

1.2.3 Land Vehicle Operation. The third category of military systems with relatively unique training device design requirements includes tanks, trucks, personnel carriers, self-propelled guns, missile launchers, air cushion vehicles, and other similar systems, all of which operate over the surface of the terrain. While each, at one level of operation or another, imposes unique requirements on the operator training system, many training requirements are common to all vehicles, particularly those for representation of system motion and visual environments. Tracked vehicles have many requirements in common: steering, engine, and transmission control and dynamics of the vehicle/surface interface. Wheeled vehicles similarly have common task and training requirements, as do most air-cushion vehicles. Unique training requirements do arise though from differences in the arrangement of control and display equipment, in the maneuvering dynamics of specific vehicles and classes of vehicles and in the tactical employment of the vehicle in performing its specific mission functions.

Air-cushion vehicles make significantly different demands on the operator than do other surface vehicles; because of the extremely low level of friction between the vehicle and the surface, the air-cushion vehicle is especially sensitive to the effects of wind and terrain slopes. This requires an unusual degree of skill and training for the operator in route selection and vehicle control. Air-cushion vehicles tend to make demands on the operator similar to those of ships and aircraft.

1.2.4 Individual Military Skills. Although most basic military skills - use of map and compass, recognition of landmarks and targets, use of individual weapons and small-unit tactics, for example, can be taught in a natural field training environment, the required, adequate environment is not always available and must be produced synthetically -- i.e., by a training device. Even normal classroom training requires devices for training control, performance measurement, guidance and student/instructor feedback at times.

1.2.5 Air Vehicle Operation. Aircraft, like submarines, operate in a three-dimensional environment and have unique, critical implications for vehicle control and operator training. The gravitational significance of the aircraft's unique orientation, and of the crew's unique perceptions and utilization of gravitational and accelerative forces in flight and systems control, makes trainer representation of these forces essential. Such representation is both complex and expensive. The need for operating high-speed aircraft close to the ground during periods of marginal controllability imposes more complex requirements on the training system representation of the crew's visual environment than for other systems where events occur at lower rates.

1.2.6 Vehicle Systems Operation. All military vehicles require operator skill not only to control speed, heading, position, path, and attitude of the vehicle, but in operation of a variety of ancillary systems (electrical, hydraulic, air conditioning, etc.) essential to the functions of the vehicle. Vehicle systems operation was considered separately from vehicle control for two primary reasons: first, most of the skills involved in system operation involve only the information available at the operator's station (where real-world visual or motion cues are involved, they tend to be limited in their demands on the training system); second, the skills required in system operation are largely procedural skills, which can be developed in settings having low simulation fidelity (8).

1.2.7 Navigation. Many military elements, units and systems require skill and training in navigation. The methods and equipment available and, thus, the specific operator tasks required vary from system to system and with mission environment. Major navigational training problems are associated with four basic techniques: celestial navigation, dead reckoning, radio/radar electronic/satellite navigation, and visual contact.

1.2.8 Gunnery. Most military systems incorporate some form of weapon -- from the personal weapons of individual personnel to the more complex artillery and missile systems. Gunnery skills include many procedural components with heavy emphasis on visual target detection, recognition, and acquisition. Flexible gunnery involves critical tracking skills, while guided-missile and fixed gunnery from aircraft require skill in complex system operation; an aircraft pilot, for example, must control both the aircraft and the guided missile simultaneously.

1.2.9 Fire Control. The employment of weapons and weapon systems involves an understanding of the capabilities of the weapon system, the characteristics of the target and the influence of a variety of environmental effects on the weapon system, as well as target acquisition, computing, plotting, ranging, sensing and, sometimes, weapon registration. It also involves, in some systems, the procedures and skills required in actual weapon launch, although these responsibilities are delegated, in some systems, to personnel not directly involved in fire control as such. Thus, the tasks of training the operator to effectively employ the total weapon system is far greater than simply training him to pull a trigger and hit a target.

1.2.10 Sensor Operation. Special sensors requiring training for proper utilization and interpretation are associated with most military systems: radar, sonar, infrared, image intensifier, magnetic anomaly, low-light-level television, and other sophisticated systems. Each system involves a series of set-up and adjust procedures and a variety of perceptual tasks requiring extensive practice and training in display interpretation. Many systems also require a detailed understanding by the operator of the effects of environmental parameters on system performance. Radar operators, for example, must be able to predict, recognize and account for effects of weather and, in the case of airborne systems, other variable influences on the display such as altitude and heading. Sonar operators similarly must learn to interpret the effects of water density and temperature gradients, background noises and variations in the structure of the ocean bottom on the sonar display.

1.2.11 Individual Tactical Operations. Significant levels of skill are required not only in operating military systems, but in employing them in the fulfillment of system mission requirements. All systems, by definition, have certain specific functions in the solution of operational problems, which require knowledge of the mission, the system and its elements, and the ability to operate the system. Most important, they require the ability to analyze specific mission requirements and environmental constraints, and to select, modify and employ system capabilities as required. A system may involve only one person and a limited number of functional capabilities, or it may involve a number of personnel and a large number of functional capabilities. An infantry scout, at the one extreme, must maintain security, must be able to navigate from one place to another, to observe and report what he sees and hears along the way, and to operate a small number of devices, including a personal weapon, a compass, and other equipment of a comparable level of complexity. The commander of a combined operation, which includes ships, submarines, aircraft and amphibious assault vehicles, is also involved in a military system, but at a much higher level of complexity. The lower level of task complexity concerns the training of operators of basic systems identified with individual military units and specific items of equipment; the higher level concerns the training of personnel in the coordinated use of a variety of systems, units and equipment. In the first case, system functions involve the employment of a weapon, a homogeneous unit such as a squad or a platoon, an aircraft, a vehicle, or any organization having a unitary identity and a discrete set of functional responsibilities. In the second case, system responsibilities involve two or more discrete units, vehicles, or other unitary systems which act in coordination in the solution of mission problems. Individual tactical operations consist of the more or less independent employment of one system, while combined tactical operations involve the employment of two or more different but related systems in the solution of problems requiring team or combined capabilities (see next paragraph).

1.2.12 Combined Tactical Operations. Most systems operate as parts of larger systems in which individual capabilities are employed in achieving functions assigned to the combined system. Personnel responsible for the employment of heterogeneous systems usually do not require skill in the operation of specific subsystems or equipment, but rather in understanding, allocating, and employing the capabilities and limitations of the available system elements in specific physical and tactical environments. Specific abilities required include:

a. Knowledge of both the nominal and degraded capabilities of elements making up the total system,

b. Knowledge of the capabilities and tactics of the enemy elements likely to be involved in each tactical situation.

c. Ability to select, modify and apply standard tactical procedures.

d. Appreciation of the capabilities of the sensors available, and the ability to derive tactical information from both discrete sensor data and combinations of data and situation history.

e. Ability to perceive relative motion among friendly and enemy tactical elements, and to predict and control the relative positions of friendly elements.

f. Appreciation of the effects, the delivery characteristics and the characteristic errors of each available weapon system.

In general, combined tactical operations require training in perceiving and controlling patterns of activity taking place over wide expanses of air, ocean, and/or terrain. Opportunities for tactical training in a real setting are limited, but many tactical situations can be adequately represented for training in a variety of effective, relatively feasible and economical ways (9, 10, 11, 12, 13).

1.2.13 Escape, Rescue and Damage and Casualty Control. Many military systems operate under extremely hazardous conditions imposed by the enemy, the mission, the characteristics of the system itself, and by the physical environment in which operations must occur. Military missions frequently require operation in bad weather, over rough terrain, under the ocean or at high altitudes, all of which in themselves threaten the well-being and the survival of the system. Many systems in employing these unique capabilities must also operate close to the envelope limits defined by safe operating practices for that system. Fighter aircraft must fly high-g maneuvers during terrain-following, weapon delivery and evasion. Submarines must operate at or near maximum safe depths to avoid detection, and ground systems must operate at high speed to achieve mobility and surprise. Thus, emergency situations arising from marginal operations can result in danger and injury to system personnel, and damage to system equipment.

Training in escape and rescue, and in damage and casualty control are both critical and difficult (5, 6). It is especially critical because of the extreme need for overlearning in task training. Training cannot be provided in the same physical and psychological environments in which the tasks must eventually be performed. In many cases, emergency skills cannot be practiced as frequently as can other normal operating skills because of the difficulty, expense and danger of providing adequate training settings. Motivation for learning emergency skills tend to be low because of their infrequency of occurrence and, for this reason, the sometimes mistaken belief that it can't happen to me!! At the same time, when emergency skills are required, their criticality and value are extremely high in terms of system mission responsibilities and equipment and personnel security.

1.3 TRAINING IMPLICATIONS OF MILITARY TASKS. Although the tasks required of military personnel vary widely with missions, systems, system equipment and the nature of the stresses under which these tasks must be accomplished, the psychological processes involved in the performance of a great many of the tasks and portions thereof are common to many operational systems. As a result, experimentation in generalized learning processes can be effective in the improvement of training over a wide range of military task responsibilities. Data on the psychological processes occurring in the development of perceptual skills could, for example, enhance capabilities for training sonar and radar operations, by further defining the manner in which complex patterns are analyzed, and the best ways of breaking perceptual tasks into meaningful, manageable subtasks for training.

1.3.1 Knowledge. In each system, crews and operating personnel must acquire knowledge related to the system mission, operating environment, characteristics, capabilities and limitations of the system, and the procedures required for its employment. Knowledge can be transferred in many ways -- from information discussion to on-the-job training. The nature of cognitive learning, particularly the inherent capability for measurement and the manner in which knowledge is employed in system operation, makes possible either individual, self-paced instruction, or group training. Both of these, in turn, permit flexibility in the selection of training approaches, and the application of a variety of automated and computer-managed training techniques.

1.3.2 Perceptual Skills. All military systems require the development and exercise of skill in the perception of mission, system, and environmental conditions relevant to the functions required of the system. Perceptual skill involves the organization of available information into patterns having meaning for the accomplishment of system functions, and the selection of procedures and actions consistent with these patterns and functions. Training in perceptual skill requires exposure to a wide variety of information concerning system capabilities and status, mission requirements and environmental influences. The specificity of responses to patterns, pattern complexity, and the difficulty inherent in defining, predicting, and measuring individual perceptual processes tend to make perceptual training difficult, time-consuming, and expensive.

The nature of perceptual processes, and the uniqueness of complex patterns in particular, require experimentation in the development of training approaches and device designs that are responsive to the requirements of specific training and operational situations.

Perceptual skills are needed in three general task areas. First, skill is required in the 1) diagnosis of system status, and full employment of its functional capabilities and characteristics. Depending on the complexity of the system, extensive training may be required to interpret data available from system indicators and system behavior, and to organize these data and correlate them with current and stored information.

Complex perceptions are also required to operate and interpret special sensor displays. Radar, sonar, infrared, low-light-level television, image intensifier, electronic countermeasures and magnetic anomaly detection systems all incorporate sensor displays producing unique, complex outputs that are sensitive to a wide variety of environmental, target, and control influences. The operator's task in 2) sensor interpretation consists largely of observing visual, aural, and other display patterns, relating them to his knowledge of the system's characteristics, the characteristics of the environment relevant to that sensor, and his understanding of the operating circumstances and their effect on the behavior of the sensor system.

The third area of perceptual skill requirement is in the 3) evaluation of the environment and its effects on system capabilities and performance. Most military functions must be responsive to change in the operating environment. The runway distance required for an aircraft to take off increases proportionally with outside air temperature and with load; a radar image of a ground target varies in size, shape, and contrast with changes in aircraft heading and altitude; and visually detected targets change in color, contrast, and distinctness with changes in time of day, haze, and smoke. The perception and evaluation of the environment and its effects is particularly critical in unaided and optically aided visual target detection, the control of vehicles by reference to immediate visual, sound, and motion cues, and in the assessment of the physiological and psychological effects of stresses encountered in system operations.

1.3.3 Procedural Skills. The perception and organization of relevant information in military system operations permits the identification and, where necessary, modification of the behaviors required to fulfill system mission responsibilities. Many of these behaviors are procedural in nature, involving relatively fixed sequences of actions on the part of the operator. Starting an engine, launching a missile, aligning a navigation system, taking up an assault formation and many other functions involve predetermined procedures. These must, to some extent, be memorized, but much of the training required in the development of procedural skills relates to performance of procedures in stressful circumstances, and to the ability to select and modify procedures according to the demands of the immediate circumstances.

Another aspect of procedural learning concerns the timing of responses. Some systems and missions impose little or no time pressure on the system crew, while others, employing similar procedures of comparable complexity, require significantly greater levels of overlearning to overcome the effects of time pressures imposed by the circumstances under which system functions are performed. Sometimes more than one procedure must be performed by the same operator during a given time period, and frequently the procedures assigned to one operator must be performed in conjunction with those assigned to other operators. Major problems in training procedural skills, once the essential knowledges have been acquired, include mastery of the proper sequence and timing of procedures and learning to recognize the effects on system status of relevant procedural steps and other influencing factors, and to modify the procedure accordingly. The simplest procedures are fixed, and require primary knowledge of the procedure, the ability to identify the circumstances in which it is required, and knowledge of the locations and modes of actuation of relevant controls. At the simpler levels, even control actuation is not a learning problem since many of the output components of simple procedural tasks are already in the repertoire of the operator trainee. As the procedural requirement increases in complexity, greater training emphasis is required in the generation of outputs and in control actuation. At the same time, greater emphasis is also required in training operators to evaluate the effects of control outputs on system condition, and to continuously evaluate the relationship of the system to its assigned functions.

1.3.4 Perceptual-Motor Skills. Perceptual-motor skills are among the most critical required in military systems. Whether they involve direct intervention in the dynamics of a system, or merely monitoring and "keeping up" with the more automated systems, they involve continuously varying relationships among cognitive, perceptual, procedural, and overt behavioral task components, frequently on a relatively well-prescribed time base. While the perceptual-motor skills required in most military systems can be described adequately at the verbal level, they can be acquired only through extensive practice in circumstances conducive to learning. The dependence of some perceptual-motor tasks on the effects of preceding inputs and on momentary events in the system environment emphasize requirements for training in rapid, accurate perceptions and in the timely interpretation of complex patterns of information and activity. Many perceptual-motor skills also appear to be heavily dependent in training on the presence and nature of elements of the operating context whose influence is difficult to predict from training situation analysis data. This produces a priori requirements for a training situation which attempts to represent the complexity of the operating situation. A major problem in designing devices and situations for training in perceptual-motor skills is in minimizing training cost and complexity by defining essential functional relationships among contextual, cognitive, and performance elements of the training and operational settings of concern, to minimize requirements for representing total system contents in training.

1.3.5 Judgmental Skills. Each system operator, to one degree or another, must make judgments concerning possible courses of action, based on his knowledge of the system, its mission and capabilities, and on his perceptions of the immediate circumstances. As in all other operator task elements, the degree of complexity of judgmental skill requirements varies from the decision-making processes required in the functions of an individual member of a simple system to those required of a commander of a combined force of air, sea, and surface elements. In each case, the decision-maker must be trained to apply available data on the status and condition of system elements, and on the mission, the enemy, and the tactical and physical environments in coordinating the actions of the elements at his disposal to accomplish assigned system mission responsibilities. He must also be trained to objectively evaluate and weigh the data available to him, both from immediate sources and from experience, and to re-evaluate basic data and to modify decisions based on the observed consequences of each course of action.

1.4 EXPERIMENTAL AREAS. Synthetic training devices help to minimize training costs in each of the five classical training problem areas--knowledge, perceptual, procedural, perceptual-motor and judgmental skills, by reducing requirements for use of operational systems and equipment in training. They tend to improve the quality of training by permitting carefully controlled exposure of trainees to the essential elements of the problems they will encounter in the operational system, and by permitting monitoring, measurement and guidance of trainee performance throughout major portions of the learning process. They also permit the development of critical skills in almost completely safe settings. To accomplish these functions, training devices must be designed to fulfill five relatively discrete functional requirements. These five requirements have been outlined to define the areas within which experimentation is required to answer design questions that have critical implications for optimizing training device designs.

1) The first development area involves requirements for the incorporation of equipment from the system operator's station in the device trainee station.

2) The second relates to the definition of the level of operating fidelity (system dynamics) required in the training device in question, or the degree to which the device must behave like the system which it represents.

3) The third development area concerns requirements for the analysis of the way in which the effects of the system operating environment are perceived and employed by system personnel, and of the manner in which these effects can be represented in training. Principal attention has been given in this category to the significance of visual, "out-of-the-window" information, and of proprioceptive and aural information in system operation.

4) The fourth category concerns the evaluation of various methods by which training may be managed and controlled, with emphasis on the allocation of instructional and training management functions among manual, semi-automatic, and automatic modes of operation.

5) The fifth category concerns the experimentation required in selecting, evaluating, and arranging components and subsystems at the device instructor's station, to facilitate the instructor's execution of all his functions.

In each of these five areas, specific attention in device development and design must be given to the influence of the task being trained for, the people being trained, the time available for training, and the possible allocations of training functions among devices, settings, equipment, and approaches. Logistical and administrative influences must also be considered to preclude the selection of designs which, while effective in training, could not be supported by the system in which they are employed. Although this latter consideration is outside the scope of the proposed simulation system's functions, it is relevant in the selection of parameters for experimental analysis.

Most training device design characteristics can be specified early in the development period, through application of training situation data generated during the development of the system for which training is intended (14). The specificity of the learning and perceptual processes and of training situations makes it necessary, however, to experimentally evaluate the logical alternatives available in training device design, to identify those that can be expected to provide effective training at the lowest cost within the anticipated training context. In effect, each device design is the result of tradeoffs among training task requirements, potential device capabilities, and the cost, safety and schedule implications of each possible approach. Effective training device development requires that adequate data for reliable tradeoffs be made available. Much of the required data concerns the effectiveness of specific device characteristics for training specific operator tasks, and is thus unique with respect to the tasks being trained, the nature of the training situation, and the essential capabilities of a variety of device design approaches.

The design of any training device assumes insight into: the nature of the task to be trained and the meaningful subtasks and elements into which it may be divided; the mechanics of the learning and perceptual processes related to each task component; the nature of a variety of possible approaches to the training of each specific task; and the economic and safety implications of potential training approaches, within an overall operational and training system context. Frequently, device designs result from "best guesses" in one or more of these areas. Occasionally, training device and training system effectiveness are compromised thereby, through lack of relevant, objective design data.

1.4.1 The Trainee Station. Each training system includes some representation of the equipment expected to be operated by the trainee as he becomes qualified. The operational work station usually includes displays of information about the status and performance of the system of which the work station is a part, and it usually includes controls which permit manipulation of the system, or portions thereof. It may also include displays or direct presentations of information about the system's operating environment, which influence the interpretation of system data and the exercise of control over the system as it operates in its environment.

While a representation of displays, controls, and environmental data is usually required for training, the configuration of the setting in which the operator is trained can vary in a number of ways, depending on the complexity of the tasks to be learned, the level of learning to be achieved in a given training setting, the manner in which tasks are segmented for training, the nature of the operational environment and the training methods to be used. It may also vary significantly with the difficulty, the cost and the criticality of representing certain aspects of the operational setting. Training in the operation of a very simple system may require only a simple, verbal description of the operator's station; a sketch, photograph, or a look at the equipment itself may suffice. For most of the systems requiring Naval Training Device Center support, however, more extensive representations are required, because the operational context is usually complex and the operator skills are similarly complicated. Chase (15), for example, has evaluated the effects of color and black and white representations of visual cues, on the performance of aircraft landing skills and has found that color influences the degree of concentration required on the part of the pilot. Decisions on the incorporation of system operator station equipment and on the degree of fidelity with which the equipment and its performance are to be represented in a given training device require similar immediate, objective data on the likely effectiveness of alternate approaches.

Another aspect of trainee station representation also requires significant levels of experimental insight. Frequently, training effectiveness can be enhanced through controlled modification of the trainee's station to provide information in addition to that ordinarily available to the system operator, or to permit the trainee himself to exercise some control over the training situation. While these tend to entail departures from trainee station fidelity, they frequently are essential to efficient training. The Army's Synthetic Flight Training System (16) and Link's GAT-3 (17) provide equipment at the student station which can be used by the student himself to initiate, control and monitor his own training. While these equipments detract from fidelity as such, they enhance device effectiveness by providing feedback and guidance without the intervention of an instructor.

1.4.1.1 Requirements for Controls and Displays. An initial decision in the development of a training device concerns the incorporation of controls and displays located at the operator station to which the training device relates, and the manner in which they should be represented. Decisions must be made about controls and displays to minimize both cost and distraction resulting from incorporation of equipment unrelated to the tasks being trained. The training situation analysis, performed in the definition of device characteristics and requirements, will answer most of the questions in this area, through definition of the tasks and subtasks to be trained in specific training settings, and identification of task-related equipment and its functional significance. Complete definition of work station equipment will frequently require objective data, however, concerning the effect of specific components on device training capabilities. In some instances, for example, the training analysis will indicate that a given display or control is not directly employed in the training subtask, but may indicate that the component could act, for that particular task, as a distractor or as a source of confusion. The degree of involvement of such components in training cannot be readily predicted, especially in systems with which operational experience is limited.

Currently, it is frequently necessary to include more of the system components in the trainee station than may actually be required, to permit early experience with both the operational system and the training device to produce a utilization concept consistent with the training requirement. As a result, many devices in the field contain trainee station equipment that has been found, through experience, to be unrelated to training. It is also not unusual for work station components to be excluded from a training device design due to limited information on their relevance for training. In each situation both training effectiveness and training cost suffer due to the inadequacy of the design data. When devices are produced for experienced operators of in-use training equipment, the problem is minimized; Silver, et al, (18) for example, found that paper-and-pencil simulation of radar pictures was adequate for training skilled operators, while more complex simulation was required for novices. The complexity and the criticality of many future systems will, however, require that devices be available for operator training prior to the employment of the operational system. Human Factors Laboratory capabilities for experimentation in device configuration will thus greatly improve the training accuracy and efficiency of prototype devices.

1.4.1.2 Equipment Fidelity. Once equipment at the operator's station has been selected, decisions must be made about the degree of fidelity of representation. Training device costs tend to increase with increased fidelity, whereas training effectiveness does not necessarily increase proportionately. Yet, while high fidelity frequently makes it easier for the trainee to relate the training situation to the operational setting, effective learning can frequently be achieved by deliberately reducing the level of fidelity, particularly in early training. In effect, fidelity requirements depend more on specific training contexts than on the degree of apparent device/system duplication. The nature of the tasks, the trainee, the instructor and the complexity of the skills to be trained dictate fidelity requirements, rather than the face validity of the training device. In fact, low fidelity may, in some instances, enhance training value by helping the trainee to recognize the essence of a task or a system characteristic. Wyener, for example (19) has noted that transparencies, wall charts and other simple aids can be used to teach the fundamentals of sonar signal classification, by parcelling out essential signal characteristics from the total acoustic complex. It may also result simply from the incorporation of unrealistic but effective learning aids, such as the breadboard trainers used in training systems maintenance concept.

Because of the many varied relationships between fidelity and training effectiveness, fidelity requirements cannot always be determined from the data available in training device preliminary design, particularly for equipment that is not directly involved in the primary tasks to be trained. This is true largely because, where objective operator task data have been generated, they tend to relate to major tasks and to tasks whose essential characteristics are more readily apparent at the early stages of system development. Many subtle and frequently critical operator/system interactions are difficult to predict during design, making experimentation in crucial task training areas significant.

1.4.1.3 Sensor Display Fidelity. Most military systems rely heavily on the ability of operating personnel to adjust, orient, interpret, and correlate information provided by one or more special sensor systems. The utilization of radar, sonar, infrared, closed-circuit and low-light-level television, image intensifiers and other specialized systems pick up, process and display essential audio and visual information, which requires extensive training in system operating procedures, and in the perception and interpretation of complex patterns. Because of the basic complexity of many of the patterns employed by the operator, the extreme difficulty in defining the manner in which they are perceived, and the current level of knowledge about the dynamics of perceptual learning, display fidelity is a significant area requiring experimentation.

Operators of radar, sonar, and similar display systems require two forms of training aside from the acquisition of information about the characteristics of the system: First, in the selection and execution of system operating procedures; and second, in which the trainee learns to modify his selection of a procedure, or to modify the procedure itself as a function of variations in the operating conditions or displayed information. The former usually does not impose stringent requirements on trainee station fidelity requirements while the latter does. High fidelity is also required when the trainee must learn to make differential interpretations of highly similar patterns.

Frequently, low fidelity is itself of significant, positive value in training, both in the employment of conventional displays and controls and of the more exotic sensor displays, where fidelity is defined as the degree to which identifiable elements of the operational system are incorporated in training device design. Training time may be wasted by requiring a trainee to recognize specific effects in a high-fidelity display before he understands them as elements of the total situation when they might have been derived from early exposure to a low fidelity representation of the display. For example, it is common practice, in the first few sessions in an instrument trainer syllabus, to lock out roll and yaw until the trainee has learned to control the pitch-related displays. Later, roll is added, to help the trainee to learn to share his attention between these two areas. Finally, maximum fidelity practice is achieved, with pitch, roll and yaw dynamics represented all at the same time.

Once a display has been selected for incorporation in a specific training device, its essential characteristics must be defined and related to the training process being implemented. Two basic problems must be solved in the definition of the characteristics of most display devices. First, the essential characteristics of the display must be objectively defined, as must the interactions among these characteristics and the inputs which produce them. Second, the manner in which the characteristics of the operational display are perceived by the system operator must be defined so that design compromises can be developed which reflect these perceptual requirements. For example, a sonar return varies in quality with variations in target type, range and aspect and with variations in water temperature and density. These variations in quality need be represented in training, however, only to the degree that they can be perceived (and/or used) by the trainee.

Definition of the characteristics of the display, and of the manner in which they are perceived must be followed by analysis of the manner in which the display and its perceived qualities relate to the training in which it is to be represented. While display fidelity is sometimes equated with the "realism" of the display, and with its superficial appearance, fidelity in training devices can be defined only in terms of those qualities which relate, either directly or indirectly, to training effectiveness.

Optimizing the relationship of display fidelity to training device effectiveness requires specific capabilities on the part of the Human Factors Laboratory. Assuming adequate definition of operational display characteristics and of their basic relationships with the operational tasks to be trained, the Laboratory must be able, first, to evaluate the characteristics of the mode of display representation chosen for specific training device utilization, and second, to specify the physical characteristics of displays to be used in training. Ideally, the latter capability should be the primary function in this area, but in practice, time and other circumstances will make it necessary for the Laboratory to evaluate existing displays chosen by a contractor in response to a specification as well as to derive essential display characteristics.

1.4.1.4 Feedback/Guidance Display Requirements. Learning, and particularly the learning of psychomotor skills, is usually enhanced by permitting the trainee to observe the results of his performance, when compared with a criterion. Feedback may, depending on the circumstances, delay learning or produce learned responses which are inappropriate. The form of feedback employed may or may not enhance learning, and it may vary in effectiveness from one stage of learning to another. In some cases, learning rates can be improved by emphasizing or enhancing the information normally available in the execution of a task. In others, it is necessary to generate and provide artificial feedback to facilitate learning, usually in the earlier stages. For example, an officer maneuvering a ship can be given quickened information, showing him where the ship would be at some time in the future if current control inputs are continued, or he could be given intermediate performance goals, each providing data on the current position of the ship and indicating appropriate control actions.

Guidance is also frequently effective in helping the trainee to recognize patterns, to select valid approaches, to sense subtle deviations from a criterion and to eliminate ineffective responses. To be effective, guidance must be relevant to the task, to the capabilities of the trainee, and to the task criteria. It must also be appropriate to the level of training and skill at the particular time it is provided. Means of devising and evaluating methods of providing, enhancing and supplementing performance feedback must be developed, to permit the development of feedback programs applicable to specific tasks, task environments, task segments, learning stages, and training devices and systems. Also, means are required for devising and evaluating guidance schemes for the promotion of effective learning.

1.4.1.5 Self-Instructional Equipment. It is frequently possible for the trainee himself to evaluate and diagnose his own performance, and to recognize requirements for further exposure to specific training material and practice in specific tasks. The degree to which self-instructional systems may be employed depends upon the nature of the learning material, how it has been segmented, and the experience and qualifications of the student. Where the nature of the training situation is conducive to student self-evaluation, and where the trainee has insight into that particular training process, trainee-initiated instruction can reduce requirements on instructional personnel, enhance motivation, and encourage the development of insight into the essential nature of the systems and the system tasks under consideration. Self-instruction may involve nothing more complex than deciding to practice a given procedure or maneuver again, or it may involve the selection and execution of any of a number of remedial programs. These programs may in turn range from library study programs to programmed texts to completely computerized programs. Experimentation in this area can define the types of programs to be made available to the trainee, and the criteria to be used by the trainee in assessing and diagnosing his own performance. It can also evaluate alternate modes of displaying performance measures and criteria, and alternate modes of providing trainee control over the learning situation.

1.4.2 Fidelity of System Dynamics. A persistent problem in the development of training devices is in the specification of the fidelity with which the operation of the prime system must be represented. In most systems, a wide variety of system, subsystem, personnel, and environmental variables determine the ways in which the system is perceived by the system operator, and the way in which it responds to operator inputs. As a result, the operator must be trained, within the limits of his capabilities, to account for the effects of many of these variables in his execution of system missions. Deciding which variables to represent in training device design requires information on the ability of the trainee to perceive the effects of specific influences on system performance, the influence of this perception on learning, and the cost of including significant perceived effects relative to the training costs incurred by their exclusion.

Experiments in the effects of various levels and types of dynamic fidelity on training effectiveness will facilitate the tradeoff studies required to develop efficient, economical training device designs. Fidelity experiments will be required in a wide range of settings, because of the wide range of operational systems requiring training device design support. Flight simulator design frequently requires insight into fidelity requirements on the system equations, because of the complexity of many of the perceptual-motor skills being trained, and because of the expense and the difficulty of generating some system data. Recently, training given in F-4E spin recoveries on the NADC centrifuge was dependent on the generation, at considerable expense, of data on F-4E spin characteristics. Initial employment of the F-4 did not anticipate a spin training requirement, and as a result, the appropriate aerodynamics data were not generated for early F-4 simulation. Similarly, requirements exist in the design of other complex systems, including submarines, land vehicles, air-cushion vehicles, and hydrofoils. There are also similar research requirements in systems not so closely identified with man/machine interfaces, including tactical and communications systems, in which the dynamics of various types of units have significance for the training of organizational command and/or control personnel at various levels. The training of traffic control personnel, infantry platoon leaders, battalion commanders, members of the division staff, fleet commanders, fire direction teams, and many other similar personnel requires some representation of the behavior of the system elements within their cognizance. Certain skill areas are particularly sensitive to the quality of information available on system dynamics. Parker and Depauli (20) found,in developing a generalized sonar maintenance trainer, that the functional similarities among a variety of sonar systems had to be accurately represented in the trainer, to permit effective training in maintenance techniques. Diagnosis of system status from observations of system performance, tracing outputs from the system, using the characteristic capabilities of system components in fulfilling mission functional requirements, and interpreting and acting on the validity of data about individual system components all imply requirements for relatively high levels of system fidelity.

Operator perception of system characteristics, and variations in the stage of training to be achieved in a given setting or device, tend to minimize fidelity requirements in some areas of training. An obvious example is the simulation of daylight. In truck driver training, a simulated daylight scene need provide no more than 10 or 20 foot-lamberts of brightness, because the driver need not learn to deal with higher, more realistic levels. An astronaut, learning to perform extra-vehicular activity, on the other hand needs to learn to deal with the high contrast environment in space, and with the glare generated by sunlight reflecting from the surface of his vehicle and his own garments. Human perception can readily integrate different sets of discrete events to produce identical effects, either because some of the discrete events in one set are subthreshold while others in the other set are sensed, or because the presence of a basic core of information suggests the presence of other information. The presence of a map symbol on a tactical display is sufficient for many purposes, for example, to indicate the presence of an infantry unit, without including a display of the weapons with which it is equipped, where these can be considered given. Perceptual constancy and perceptual filling can greatly modify otherwise predictable responses to both operational and training situations permitting relatively low fidelity where requirements for high fidelity would normally be expected. Analog displays of vehicle system performance can be driven by digital inputs, for example, simply by choosing data iteration rates above the operator's threshold for discriminating them. Physically, the fidelity with which the simulated display represents the operational display is low, but from the point of view of the operator, it is high.

The stage of training to be provided in a given setting also influences the degree of dynamic fidelity of the training device. Fidelity can be less than perfect during the early stages of training and when operator skills are relatively simple.

An additional problem in the specification of dynamic fidelity is in predicting the attitude of the trainee with respect to the training system itself. Most training systems are perceived, first of all, as non-operational systems which require different attention sets and responses than do operational systems. More specifically, trainee stations are frequently perceived as learning settings, making it difficult for the trainee to work for operational proficiency because it sometimes seems to interfere with training device proficiency. As a result, he tends to respond to those aspects of the training situation which seem able to contribute to his ability to obtain a passing grade in training. For this reason, recognizing the criteria against which his learning performance is evaluated, the trainee tends to ignore variations in fidelity which would distract a skilled or experienced operator. Trainees become adept, for example, at identifying ways of flying low fidelity instrument trainers to achieve scorable performance. Sometimes heading can be maintained best by crossing controls in contrast to acceptable practice in the aircraft, where this would be dangerous, and contrary to habits established in long experience in the aircraft. Also, a study by Miller and Goodson (21) found that in a fixed-base helicopter trainer, skilled instructor pilots experienced motion sickness, but that trainees suffered no discomfort. It was concluded that the presence of visual cues to cockpit motion, in the absence of the vestibular cues expected by the instructors, was responsible for the instructors' motion sickness. By the same token, where training situation and operational performance criteria coincide, as they usually do, trainees still tend to attend to the stimuli and stimulus patterns, and to the organizations of those patterns, which appear to improve performance, even though they may not appear "real." As a result of the impact of fidelity of representation and system dynamics on human performance and learning, a significant number of experiments performed in the ETSS are likely to be concerned with the selection of fidelity levels which are consistent with specific stages of training, with trainee perceptual capability and with the economic return of various fidelity levels.

1.4.3 Environmental Fidelity. A major problem in the development of any training device is in the definition and representation of the operational task environment. The system environment not only provides some of the stresses to which the operator must adjust, but it also frequently provides much of the information required by the operator in performing his assigned tasks. Appendix C summarizes some of the more significant training implications of operator station motion and real-world visual cues, as they are encountered in the four classes of systems reviewed.

Frequently cost, safety, and practical engineering considerations make it impossible to reproduce all characteristics of the environment that seem relevant to the training and execution of essential operator tasks. Even more frequently, however, it is difficult, if not impossible to justify the incorporation of some aspects of the environment on the basis of training relevance. For one thing, past experience indicates that all of the environment need not be represented for effective training. In flight simulation, for example, (22) the onset of a cockpit translation contains almost all of the information needed by the pilot in responding to that translation; the translation itself can be deleted from the simulation, at no cost in training value. It is also apparent that due to the nature of human perceptual processes, effective representation of the environment rarely requires complete reproduction of environmental effects. The most obvious case in point, perhaps, is the use of color film, which while not truly realistic, is adequate to represent natural colors for most training purposes. Another is the use of a rapid sequence of still photographs to represent object motion. Less obvious, but equally significant, is the adjustment of work station motion components to make limited movements represent motions of much greater magnitude.

Highly significant interactions appear to take place among specific environmental stimuli and tasks, and in the perceptions of combinations of environmental effects. Recent experiences with flight simulators indicate, for example, that cockpit motion cues are perceived and used differently when out-of-the-window visual cues are present than when they are not available (23). There is also some indication that specific systems for representing environmental cues may be appropriate for one task and not another. This is particularly evident in visual simulation where the resolution, color, or field of view provided for training in one task are not adequate for another. Basic driving instruction, for example, requires only that the trainee have a visual reference to help him to sense the effects of steering while moving, braking and accelerating. Advanced driving, however, requires that he be able to select a route consistent with the capabilities of his vehicle, based on the slope of the terrain, the consistency of the bearing surface and other data involving greater information-coding capability than that required by the simple learning task. A similar effect appears to occur in the simulation of work station motion, where the rates at which roll motions are "faded back" to neutral in coordinated turns are effective for training instrument flight skills involving only moderate maneuvering. The same rates, however, provide false cues when more rapid maneuvers are being trained.

Five R and D issues require attention in the development of concepts for the representation of environment characteristics in training devices:

1) Sensory Thresholds - Even though a system operator may not directly employ a particular environmental stimulus in exercising system control, the stimulus may act as a distractor, as a source of stress, or as a source of confusion in identifying the stimuli to which attention should be directed. It is necessary to establish not only the absolute thresholds for stimuli which might thus be significant in training, but to determine the extent to which the threshold is influenced by other stimuli sensed at the same time. It is conceivable that data on thresholds for discrete environmental cues and combinations of cues could be effective in predicting trainee

perceptions in complex environments, facilitating the selection of cues for training device representation. Since thresholds tend to vary widely with the nature of the stimulus context, a critical category of experiment in this area should evaluate the influence on performance and learning, of various stimulus values and combinations. This would help to establish requirements for the incorporation of stimulus capabilities in device design, based on their functional significance. System and environmental sounds may be found to facilitate performance involving instrument interpretation, for example, or they may be found to distract the operator sufficiently to justify their deletion in some stages of training.

2) The Selection of Significant Cues (Stimuli) - Specific information is frequently needed, in the design of a training device, about the manner in which environmental stimuli are employed in learning and executing specific tasks. Usually, not all of the stimuli available in the environment can be reproduced in the training situation. As a result, experimental analysis is required to identify functional relationships among environmental stimuli and the tasks to which they may relate. For example, the level of fidelity required in the simulation of sonar signals depends on which characteristics of the signal are employed by the sonar operator. Some apparently critical signal aspects may, in reality, need not be represented. By the same token, signal characteristics which appear insignificant may be found to be essential to specific training tasks. Mackie and Harabedian (24), for example, suggest further detailed analysis of recorded sonar target characteristics, in the definition of features to be incorporated in synthetic target generation, because of the subtle nature of the passive sonar classification skill.

3) **Representation of Cues - The incorporation of environmental stimuli in training devices can only rarely be** accomplished by using the real stimulus itself. As a result, relevant stimuli and stimulus patterns must usually be represented in some artificial manner. In many instances, a variety of potential means is available for representation of required environmental information, but in most cases each of these means will provide adequate representation of only portions of the cue characteristics considered essential for training. At the same time, each will tend to provide extraneous information whose effect on training must be defined in selecting the final mode of cue representation. The basic problem is in selecting the mode which retains most of the essential cue characteristics, provides as few significant

extraneous stimuli as possible, and is at the same time feasible, practical, and economical. A good example is in the simulation of extra-vehicular visual cues. Point-light source systems are effective in the simulation of elementary steering tasks for drivers of surface vehicles, since they can accurately represent two-dimensional relationships. They are inappropriate for training weapon system operators in target acquisition, however, because they lack resolution, brightness and contrast. Similarly, camera-model systems are appropriate in aerial navigation training, but may not have adequate depth of field for training in many close-to-the-surface operations.

4) Cue Interaction - Environmental cues, particularly visual, motion and sound cues, tend to interact with each other in providing the operator with information on the status and the behavior of the system with which he is concerned. Effective training device design requires that the significance of these interactions be established, particularly when only certain aspects of the stimulus environment can be represented. Care must be taken to incorporate in the device not only the stimuli required for training specific tasks, but the essential combinations of stimuli as well. In addition, it is important that the essential, perceived pattern of cue combinations actually represent those experienced in the work station. A tactical commander, for example, responds not only to immediate data on the status and position of the units under his command, the disposition of the enemy and the nature of the terrain, but also to his knowledge of the action so far, the past performance of his own and the enemy's units and the capabilities of adjacent and supporting organization. Knowledge of the effects of this information must be available to the training system designer, in determining its relevance for a specific training mission.

5) Cue Substitution - When an essential cue cannot be provided in a training device, for economic, safety or practical reasons, a totally artificial cue or one derived from the general, operational stimulus complex, can sometimes be substituted. Task meaning is attached to such cues through intellectualization of the training process. The trainee knows that the cue is atypical, but he also knows that the real cue he will use in system operation will vary in the same manner as the artificial training cue. At the simplest extreme, telling a trainee when to begin or end a particular task sequence frequently replaces a whole complex of cues which would contribute little of value to the learning of a

specific task. Another example of the concept is the use, in flight simulators, of a trapezoid figure to represent the edges of a runway, in teaching landing skills. Many more visual stimuli are present in the real world, many of which can be used in judging altitude, glide path, drift, heading, touchdown point, ground velocity, and sink rate. Training the student to land using only the runway outline permits him to learn some of the key perceptions useful in landing, and also permits him to develop the required psychomotor skills in relation to these perceptions. When he lands an aircraft he can relate the visual cues used in training to their correlates in the real world, using them and the other available cues to improve his capabilities in circumstances where the cues used in training are not as evident, and other, non-simulated cues are more relevant.

While it is apparent that some cues, representing a core of information essential to the development of specific skills, may be taken out of context for training purposes, it is rare that this can be done without significantly modifying the perception of the cue. Without all of the cues ordinarily available in landing, for example, the size of the runway defined by a simple trapezoid visual pattern is likely to be misjudged if realistic geometric relations are used. Modifying the perception of a cue used in a control skill can thus modify the way in which the skill is exercised, requiring two skills to be learned: the first being the specific skill required in operating the training device; the other the translation of that skill to the operational setting. The problem can be avoided by rescaling the out-of-context cue to permit the development of skills appropriate to system operation, and not peculiar only to the training device. Flight simulator motion systems cannot economically provide some of the motion cues occurring in aircraft. As a result, motion onsets have been employed to provide the essential proprioceptive cues required in flight control. It has been determined experimentally that these onset cues must be enhanced to provide the kinds of perceptions required to develop essential control skills, at least in pitch (25). It is apparent that the dynamics of human perception will require specific experiments to fit specific cueing arrangements to specific training device requirements. A typical experiment in this area might evaluate the relative efficiencies of artificially enhancing hard-to-simulate visual cues in a driving simulator. This could obviate the need, in early procedure training, for simulating otherwise subtle color, shading, contrast and motion parallax cues to surface texture and scope essential in skilled driving performance. The experimental approach would permit the "side effect" of such cue enhancement and substitution to be specified and controlled prior to final device design.

Environmental simulation includes the simulation of the motion of the work station, the visual scene outside the work station, the sounds which influence the performance of the system operator, and the odors which may influence his behavior. Specific simulation, training, and training device problems accompany each area, requiring the generation of experimental data relative to the incorporation of apparently significant environmental cues in training in the development of particular training devices and systems.

1.4.3.1 Work Station Motion. Motion of the work station can act as a distraction to the operator, and it may also provide him with cues useful in the performance of his tasks. It may also constitute a source of stress and it may make certain tasks more difficult, requiring the development of compensatory skills. In each capacity, motion has significance for training, which must be defined in the training situation analysis for each training situation. Once the significance of motion for training a specific task has been established, the method of providing adequate motion cues must be established, either through extrapolation of relevant past experience or through experimentation with essential portions of the training situation.

Motion stimuli relevant to operator performance can occur along and about each of the operator's three body axes. There are some motions to which the operator is insensitive because of the low level of change involved. Sustained velocities are not sensed, but accelerations can be sensed as they occur along any of the three axes, provided they are of sufficient magnitude. Motions about each axis are also sensed, if they exceed the sensory threshold, for as long as they occur; fixed positions established about two axes are similarly sensed. Thresholds have been established for many of the motions along and about the three axes (26), but employment of these threshold data in the prediction of responses to motion in operational and training systems is extremely difficult. It is, therefore, necessary that experiments be performed to establish motion thresholds in task and training contexts in which stimuli other than motion are present.

All of the motion cues relevant to operator performance and training cannot be provided in ground-based training devices for practical physical, economic and safety limitations. Thus, means must be established for representing certain motion components to permit effective, valid training. Sustained acceleration along the longitudinal, lateral, and vertical axes produced by speeding up or slowing down a vehicle, by dropping it or lifting it or by turning about one or more axes over extended periods cannot be adequately represented. Attempts have been made to simulate sustained longitudinal accelerations by pitching the operator station, using the resulting gravity vector to produce appropriate proprioceptive cues. Seat belt and shoulder harness tensions have been manipulated to provide some of the stimuli accompanying sustained acceleration, and inflatable seat cushions have been used to provide some of the sensations accompanying pitching, rolling, and lateral translation. Insufficient data are available to permit direct application of any of these techniques to specific devices intended to train specific tasks. Again, experimental data are required to determine the best method of providing the motion information required to train specific skills.

1.4.3.2 Real-World Visual Simulation. Many training devices, particularly those concerned with training vehicular and weapon control skills, must incorporate representations of some aspects of the operator's visual environment: First, relatively discrete aspects of the visual environment, likely to have more or less independent implications for operation and training, must be defined through analysis of the tasks to which they may relate; second, their specific relationships to training must be defined through analysis of experience with similar systems, through interpretation of pertinent research literature and through experimental evaluation of the influence of specific visual scene elements on effectiveness in training specific tasks; third, when visual stimuli appear essential to training but are limited by cost and/or infeasibility, means must be developed for assuring overall training effectiveness by substituting artificial for more realistic visual cues, and by reallocating training functions among devices and operational systems to assure development of essential, visually related skills. Little formal experimentation has been conducted in the differential allocation of training tasks between devices and operational systems. It should be possible to optimize training effectiveness and cost by systematically varying the amount and type of training given in, for example, a diving trainer and in the actual **submarine** diving station.

1.4.3.2.1 Visual Cue Fidelity. Much of the laboratory requirement for developing training device visual cue capabilities is in the analysis of visual cue fidelity requirements. The requirement is essentially that of identifying the detailed aspects of the visual cues considered pertinent to the training of a specific task which influence training effectiveness. While visual "realism" is frequently employed, at least informally, as a criterion of visual cue fidelity, the significant criterion is the ability of a system to promote transfer of learning from the training setting to the operational setting. While subjective realism tends to influence device training value by way of its motivational value, the majority of training effectiveness depends on the ability of the visual scene to provide information essential to the task being trained. It is not likely, for example, that a navigator can learn to make celestial fixes without having a star representation available to him at some point in his training. Task-related information must be identifiable, must be capable of being recognized as a representation of corresponding pertinent information in the real-world visual scene and, most important, must appear to the trainee to vary in the same way as the real-world cue would vary under the circumstances represented.

Frequently, it is possible to selectively extract essential cues from the total visual environment and present them economically in a training device. A tank gunner, for example, can learn most of the skills required in target acquisition, gun laying, ranging, tracking, firing, sensing and adjusting, using a target consisting only of an outline of a real target; he does not need a real target for the bulk of his training. Occasionally the process of extracting and synthesizing cues involves significant, albeit inadvertent, perceptual modifications that might influence training by changing the cue context and, hence, apparent cue-related behavior. It is important that these changes and their effects be defined prior to device development, so that the cue may be scaled to produce the desired performance and training results. In effect, all representations of visual scenes are extracts of the real-world and as such, behave differently from the real-world scene, either grossly or subtly. Simulation problems arise when the simulated cue or scene appears adequate but produces subtle differences in performance. If the size of the target is inappropriate, range estimates may be made incorrectly, or if it has the wrong outline, its type, and thus its speed characteristics may be misjudged. Many common perceptual constancies and contrast effects must be considered in synthesizing cue contexts through the extraction of individual cues which seem relevant or whose principle utility is in their ease of simulation. This may occur in straightforward situations in which control is exercised only through reference to the visual display itself, or it may occur only as an apparent conflict between visual and other cues, such as motion, sound or instrument cues and produce vertigo or inappropriate learning.

Specific characteristics of visual cues appearing to have significance in a variety of training situations include resolution, color, field of view, stereoscopic capability, depth of focus and image motion. Other characteristics deriving from the means of display selected for the training device are also significant and require special attention. Point-light-source systems, for example, produce geometric image distortions; film systems tend to produce a grainy texture; and camera-model systems are generally limited in luminosity. Each accompanying characteristic must thus be evaluated as a part of the total training context.

Requirements for specific visual cue characteristics must be specified from the analysis of the task to be trained. Training-significant task elements are allocated among possible training settings, devices and equipment based on current knowledge of training capabilities in the relevant area but, during this allocation, there is a strong tendency to emphasize task requirements that have relatively firm correlation with the training and device state of the art. There is a tendency, also, to require a greater visual simulation capability than is actually required for effective training, due largely to the difficulty in precisely defining visual cue requirements in training specific tasks and to the desire for "realism" in the visual scene. Visual cue requirements frequently appear more significant in initial analyses of the task to be trained than is found to be essential for effective training once the task has been related to the specific training setting. Binocular visual cues, for example, might at first glance appear critical in piloting but in fact are not, since objects used for visual reference are usually at some distance. They are probably not employed at all except in formation flight and in-flight refueling, where maneuvering is performed relative to close objects. The experience of one-eyed pilots, and experiments with the deletion of binocular cues in airplane landing (27) tend to support this view.

Current experience in visual simulation strongly indicates that the purely visual aspects of target detection cannot be simulated, due both to limitations in the displays available and to problems in defining the influence of visual elements and interactions among elements on operator performance. The most effective training in target detection employs a sequence of settings: 1) classroom orientation is provided on the nature of the detection problem, the nature and effects of variables influencing detection and on the procedures to be employed both in visual search and in response to a detection; 2) a procedures trainer is sometimes employed to provide practice in the execution of appropriate procedures; 3) a system simulator may be used to train the dynamic skills required to maneuver around and engage detected targets, where a vehicle system or a maneuvering unit is involved; and 4) training in detection must culminate in real-world exercises with field training comprising all essential parts of the total system.

The allocation of training subtasks to specific settings must result in the utilization of specific, relevant, feasible and economical capabilities of each setting, both for efficient presentation of training material and for the efficient control of the learning process. In the development of most training devices, it is necessary to develop a system of mutually interacting training settings, rather than attempting to develop specific devices to support discrete task elements considered to be outside the total training context. Experimentation is a major part of the development process in providing objective, relatively immediate data on the training significance of specific task requirements and on the capabilities of all of the available devices and training settings. Training economy and training efficiency would both be optimized if experiments could evaluate the relative merits of relying on various proportions of device and vehicle time in training driving skills. A representative experiment might measure the effect on later performances, of assigning the majority of training to a driver trainer, or to an automobile itself. Data from such an experiment would reveal the training value of each approach, which would in turn have implications for training cost.

1.4.3.2.1.1 Visual Cue Elements. One of the more obvious requirements in the generation of visual cues for training is for resolution of visual detail. The level of resolution provided determines the fidelity with which object sizes, shapes and contrast gradations are represented. Resolution thus has significant implications for operator training to the extent that size, shape and contrast are significant in the learning and execution of operational tasks. While it is generally understood that the training effectiveness of visual simulation devices is more or less directly related to the degree of resolution they afford, problems in providing adequate visual detail are usually associated with defining the minimum resolution requirements for representing task-related elements of the visual environment, and in selecting a visual display mode or a combination of modes that provide the levels of resolution required. Basic cue requirements are derived from analysis of operational tasks, but final implementation of cue requirements in training device design is ideally the result of design and training tradeoffs among alternative approaches, based upon objective experimental data. Considerable attention has been given, for example, to the relative merit of black and white and full-color visual simulation of real-world visual cues. Chase (15) has analyzed the value of color in aircraft landing training, but it has implications for many other areas of training, both in flight skills and in the operation of other complex systems, such as in ship operation, tank driving, target acquisition and gunnery.

Color is essential in the execution of some complex tasks, and must be incorporated into the design of training equipment for such tasks. Color is of special significance where different responses are made to colored signals, and color contrasts, when subtly used, may also be effective in training many tasks, even in establishing the "acceptability" of a training device. While acceptability does not often relate closely enough to training value to justify its expense, color may add enough realism to convince the trainee that the degree of correspondence between the device and the operational system warrants its use in the development of operational skills. In these instances, requirements for the presence and the quality of color in the device visual scene can be established best through experimentation within a representative training task context. Colors, aside from those used as signals, interact with operator tasks by facilitating the identification and differentiation of objects. In some systems, they may facilitate accurate judgments of object distance by varying with atmospheric attentuation. In many systems, the influence of color on performance and training is unknown, and objective definition is required before specific design decisions can be made.

Field of view, depth of focus, light variations across a visual scene, the significance of binocular and monocular viewing, image registration, and visual system exit pupil size can also influence the quality of specific systems for operator training. The approach employed with respect to each of these areas of consideration must be directly related to the tasks being trained and to the overall approach used in training.

1.4.3.2.1.2 Visual Display Modes. In each area of training device design, training effectiveness depends heavily on the peculiar capabilities and characteristics of the mode of simulation chosen. Each mode has its own specific characteristics, some of which make some aspects of visual simulation easier than others. For example, film techniques permit good color rendition and good resolution of detail, but limit the field of view and the degree of control exercised by the trainee. Point-light source visual systems have great flexibility and wide fields of view, but poor resolution and poor rendition. Television systems are also quite flexible, but tend to have narrow fields of view, short depth of focus, low light levels and relatively poor resolution.

Selection of the proper display mode for training specific tasks requires not only that the task cue requirements be carefully defined, but that the capabilities and limitations of each potential method of cue generation be understood. Ideally, it should also be possible to quantify the relative costs and values of using each mode to permit the selection of mode to be based not only on lowest incidence of undesired features but also on the relative training decrement resulting from each of these features. Much of the matching required between cue requirements and display capability can be performed analytically, but the difficulty of defining cue requirements, especially for training operator tasks in novel systems, and the difficulty of relating specific aspects of a display characteristic to these task requirements necessitate that final selection of a display mode be accomplished through objective evaluation of potential modes within critical task contexts.

1.4.3.3 Sound Simulation. Many of the sounds produced by system equipment and by the operating environment are significant in the learning and execution of system operating tasks and must, thus, be represented in training device design. Sound fidelity requirements have significant cost implications and, thus, must be established for each training task and device. The specific characteristics of system sounds must be established experimentally in the areas of application discussed in the following three subsections.

1.4.3.3.1 Presence/Absence of Sound. System sounds may influence the operator in three basic capacities: 1) as distractions that force the operator to attend to more stimuli than are directly relevant to his task; 2) to mask or distort his perception of sounds essential to the execution of specific tasks; and 3) to represent or contain information directly related to task performance. In many instances, sounds act as indicators of system and subsystem status, providing immediate information sometimes not available from other, more formal sources. In some aircraft, for example, lack of noise associated with the periodic build-up of pressure in a hydraulic accumulator can be an early cue to a malfunction. In a remote-control weapon system, the sound of weapon firing may be an essential cue in assessing system operability. Similarly, the background noise in a tactical communications net, or its absence, can have significance in informing a commander of the status of the net and of the units which it links.

Sounds cannot only degrade operator performance by their distracting quality, but can also degrade training effectiveness if incorporated at the wrong point in training. Experimental data are required to establish the point in training at which specific sounds distract the trainee and the point at which they provide data essential to training. A trainee learning to drive a truck in a driver trainer, for example, may be distracted by engine and transmission sounds during the period in which he is learning basic driving and gear shifting procedures. Later, these same sounds may be critical in helping him to apply those procedures in the development of more advanced driving and transmission control skills. It is currently common practice for sound simulation to be deleted during those periods in which it would detract from training but unfortunately it often continues to be deleted during periods of need.

1.4.3.3.2 Sound Correlation. To be effective in training, system sounds must be correlated with other information available to the operator and with his responses. Again, complete correlation could be of negative value at certain points in training, but a basic capability for sound simulation within a total training context is significant. The sounds generated by current training devices are generally regulated by the instructor, who decides whether the sound is required at a given point in training or not and the amplitude at which it should be represented. In the process, the correlation of sounds with other events in the training situation is frequently lost or distorted. Experiments in the programming of aural instructional information will be required to establish optimum degrees and modes of sound correlation and instructor-independent control.

1.4.3.3.3 Sound Composition. Most sounds are made up of a mixture of periodic and aperiodic components, each of which contributes to the perceptual impression made by the sound as a whole. Particularly in the case of the sounds heard by a sonar operator, the composition of the sound is significant in the identification of the sound source and in evaluating the influences of the propagation medium and background sources on sounds and other operationally significant phenomena. Attenuation, distortion and displacement of a sonar ping by temperature gradients, for example, provide data useful in selecting the right depth for concealment of a submarine and, by the same token, data relevant to the selection and employment of other means of searching for a concealed submarine.

While the composition of sounds employed in system operation can be relatively easily established, knowledge of how sounds are perceived, analyzed and employed by human operators is limited, limiting in turn the ability of the training device designer to establish required modes, levels and costs of sound fidelity. In deciding whether and when to provide a sound, experimental data must be made available to determine the level and type of sound complexity required in learning specific sound-related tasks, and the levels of complexity appropriate at specific stages of training. Some radar operators have said that they can diagnose problems in the radar set by listening to the sounds it makes as it operates; good automobile mechanics also learn to use sounds in the diagnosis of engine and system performance, interpreting cues which are essentially unavailable to the untrained. Effective training in such perceptual skills requires detailed analysis of task-associated sounds, and of their implications for training, through their controlled introduction in experimental training situations.

The major implications for ETSS design, of the area of environmental simulation lie in the little-known relationships among environmental stimuli and operator perception, learning and performance. These relationships are unknown due largely to the specificity of task situations, and to the multiplicity of ways in which these situations can be organized by the perceptual processes of the human operator. In specifying the approach to the simulation of each environmental cue, the designer must have data, hopefully from formal studies, which define the effect on trainee performance of each cue and combination of cues relevant to the stage of training under consideration.

1.4.4 Instructional Management. Training in complex knowledges and skills begins from what the trainee already knows or can do, progressing gradually to incorporate more and more knowledge and abilities in his repertoire. Training programs in general attempt to divide training into manageable, meaningful segments that can be readily grasped by the trainee and incorporated in his repertoire. They also control the rapidity with which the trainee faces complex performance problems, and they modify the training approach consistent with immediate trainee capabilities and progress. Recent developments in training management have made it possible for much of the work involved in these functions to be performed automatically with a minimum of direct involvement of instructors and other training personnel. This has produced more efficient, less expensive training, and to some extent more objective trainee guidance and evaluation. Future trends indicate greater advances in the objectivity of training control, continued modification in the functions to be performed by the personnel responsible for training and, perhaps most significantly, greater requirements for the derivation and application of analytic techniques that can provide objective data on operator performance, learning and learning control.

The implementation of programmed instructional techniques requires the timely generation of objective task and training data, and the development of programs specific to the training device or system under consideration. This is not essentially different from the traditional approach to training device development, except that the development of the device characteristics essential to programmed instruction must be accomplished much earlier in training system development than has traditionally been the practice. Once device characteristics have been defined, they are difficult to modify; design decisions relative to programmed instruction must frequently be made early, and they must be more nearly correct than when programming is left to the ingenuity and the flexibility of the instructor and his lesson plan.

Most data required to implement programmed instructional techniques in training device design are available from training situation analysis, and from classification tests given trainees in their selection and assignment to training. Other information relevant to some aspects of training is also available from the training given in similar systems prior to the situation under consideration. Significant amounts of data are required, however, pertaining to the operational system for which training is to be given and to the training situation anticipated. A major function of the experimental simulation system will be in providing information essential to the development of specific instructional programming capabilities. Experiments are anticipated in the development of performance measures and methods of exercising control over the training process.

1.4.4.1 Performance Measurement. Measures of trainee performance compared with each other and with similar measures of skilled performance can reflect rates, levels, and directions of learning and the quality of the learning situation. They can also be used to diagnose learning problems and to suggest approaches to the guidance of learning. For these reasons they are crucial in the development and implementation of training.

A major problem in the measurement of trainee performance and in the interpretation of these measures is in establishing their validity for system operational performance. Much of the validity must necessarily be established through rational analysis of system performance information generated in the training situation analysis, and through analysis of possible methods of producing criterion performance. Significant additional data must be developed, however, through experimentation in relating performance and learning in restricted learning situations to performance in the prime system. Successful operator performance in a new system can usually be reasonably well defined through analysis of performance on similar systems currently in operation. These performance predictions can usually be further refined through experience with the prototype system. Estimates can be made similarly of the nature of the systems, devices and programs likely to be effective in producing acceptable levels of operator performance, and many of the measures of learning and performance employed in current, similar training situations can be analyzed for applicability. In the final analysis, however, it will be necessary to collect data that reflect learning conditions in settings relevant to specific systems and system tasks, and that can be employed in evaluating and guiding training.

Training in the present context includes the acquisition of both knowledge and skills. The measurement of knowledge is relatively straightforward, assuming an adequate definition of essential knowledge. Standard paper-and-pencil measures can be employed and data can be readily analyzed using simple computer techniques. Skills can also be measured, but more complex insights, procedures, and equipment are required to assure identification of significant skill components and to permit measures of these components to be made and evaluated. Many different aspects of a given performance can be measured and recorded. Many aspects may be highly correlated with each other, requiring measurement of only the more convenient. Some aspects may more accurately reflect learning than others, while some may be more reliable predictions of operational performance than others. Critical experiments must be performed to clarify these points with respect to the design of specific training situations. Particular attention is required, in analyzing the skills involved in operational performance, to identify skill components which relate directly to skill level, and which are at the same time accessible to measurement in training. Once appropriate components have been identified, means of measuring them in training must be defined. Frequently, it will be necessary to develop measures which cannot be related directly to system operation, due to the newness of the system, or to its inaccessibility to the device design team. When operational skills are well-defined, experimentation can establish the most reliable, valid, accessible and economical performance measures to be employed in training evaluation. When these skills are not well-defined in the operational setting, experimentation can establish correlations among individual behaviors occurring in the training setting and between these behaviors and total performance. These experiments can establish reliable performance measurement approaches which can later be validated when performance in the operational system can be assessed.

Once methods of measurement have been defined, schemes for their mechanization and utilization must be established: first, training device design must permit measurements to be made; second, it must permit measurement without disrupting training; and third, it must provide performance data in forms consistent with their intended purposes. The identification of the performance parameters to be measured is a function of the training situation analysis. The development of ways of measuring without disrupting training and of ways of employing performance data are functions to be established by a capability like the ETSS.

In most cases, training devices can readily permit measurement without trainee distraction. When a computer is a part of the device, performance information is frequently available through interfaces with the computer program. In many training devices, synthetic system outputs which are influenced by trainee performance and the conditions under which they were generated, are or may be recorded. Most training devices and systems permit instructor monitoring of system status and trainee performance to provide useful data for the guidance and evaluation of performance and for evaluation of the training approach itself. Frequently, however, special means must be provided for collecting and organizing information essential to training. Training is frequently facilitated when the conditions of practice can be adjusted to aspects of trainee performance which are not directly reflected in the usual measures of learning progress. For example, the score achieved with a given round fired in marksmanship training is a gross measure of performance; but does not contain enough information by itself, to permit adequate guidance in improving performance. Additional data on whether the trainee flinched, whether he jerked the trigger and where in the sighting training-firing cycle these events occurred could be of significance in improving his performance on subsequent shots. If, in turn, these data could be related to earlier performance in related skills, even more appropriate guidance could be provided. In these situations, it is essential that the measurement and the training processes interact to enhance training. Sometimes this interaction may be intimate, as in the employment of the same data for feedback as is recorded or displayed for evaluation. It is frequently possible for measurement to detract from training value if it delays or interrupts training, if it provides undesirable information to the trainee, or if it provides information at the wrong time or in wrong form.

When complex performance is involved, performance feedback may occur too late to be of real use, due to the limitations of the display or hard-copy equipment available. In air-to-air gunnery, for example, the trainee must wait for a tow-target to be scored, or for gun-camera film to be developed and projected, before he can relate his gunnery performance to his actions in the gunnery pattern, making this form of feedback nearly worthless in establishing correct aiming and target-leading behaviors. Sometimes, even the overt act of measuring performance, if the trainee is aware of it, can influence training progress. The trainee who is aware of being observed may decide to "go by the book" rather than using imagination in a decision-making situation. By the same token, the trainee who knows his performance is being monitored is more likely to attend to details than to one who knows that only his final performance will be examined. The measurement process may even prevent the trainee from receiving essential, timely information.

Usually, the display, processing and recording of data available in the device computer need not interact with the trainee or with the training process as it is perceived by the trainee. Problems arise when displays, printouts and records that form a normal part of the operator station are annotated or processed to adapt them to performance measurement and recording. When the processing modifies either the data or the training procedure, experimental data on the training effect of these modifications must be gathered to assess the degree and mode of disruption of training. Ordinarily these problems will require little experimentation, provided adequate training situation data are available in the development of device specifications.

The measurement of performance in the ETSS will take a number of forms, because of the variety of tasks and task elements within its area of responsibility. A considerable amount of measurement will consist in the evaluation of paper-and-pencil data generated by the subject. Other data collection will involve more elaborate hardware and programs which in turn will account for a significant amount of cost and system design effort. The areas having the most significant cost implications are in the measurement of perceptual skills, procedural skills, perceptual-motor skills and judgmental skills.

1.4.4.1.1 Perceptual Skills. It will be necessary in the evaluation of effectiveness of approaches to training of perceptual skills to measure subject responses. Perceptual training usually involves presentation of patterns of stimuli to which the subject must make a defined response, recording of the responses and analysis of responses to reveal perceptual modes and learning trends, rates and levels.

Major perceptual training requirements include those for radar, sonar, ECM, MAD and infrared interpretation. Also, unaided ground-to-air and air-to-air aircraft recognition training will continue to be significant for the foreseeable future. Unaided and optically aided air-to-ground and ground-to-ground target detection, acquisition and recognition will also continue to be major training problems. In each of these areas, relatively few efficient methods of synthetic training or performance, have been developed to date. Most perceptual training is given through exposure of the trainee to situations that he must interpret, or to limited segments of the situations, which require him to identify essential characteristics by becoming familiar with essential elements one at a time. Most synthetic training approaches have been limited by the capabilities of the display media available, and by attempts at using the necessary limited capabilities of various potential training approaches for training total perceptual skills. Very few attempts have so far been made at defining skill elements that are both meaningful and compatible with the capabilities of available training and measurement techniques. Requirements for experimentation exist in two areas: 1) in defining essential elements of perceptual skills required of operational personnel; and 2) in relating these elements empirically within a training device context and within a training system to permit development of training situations and measures that are not only within the device state-of-the-art but that also facilitate training in logically defined skill elements.

1.4.4.1.2 Procedural Skills. The development of skill in the execution of procedures must also be measured to permit effective training. Many military operations require execution of fixed procedures, some of which are required in the operation of system equipment, some relate primarily to communications while others are concerned with tactical employment and maneuvers. All procedures have a requirement in common, for the execution of a relatively fixed series of actions. For most of these, the requirement is that these actions be initiated at a particular time or in relation to a specific event, and that each procedural step be executed at a specific time. In some cases, it may be necessary to modify a selected procedure in response to modifications in the operational situation. Procedural skills may be evaluated, then, in terms of the time and event at which they are initiated, the order in which procedural actions occur, the time required to execute procedures that must occur rapidly, the correctness of each procedural step and the ability of the trainee to modify procedures as required.

1.4.4.1.3 Perceptual-Motor Skills. Many systems require crew responses that are, essentially, the result of continuous sensing, organization and integration of data from a variety of sources. A rifleman, for example, uses range information obtained from his own perception and/or from a mechanical source, plus ballistic information and lead data from memorized sources and/or from experience, together with his visual and muscular skills in aiming at a target and squeezing the trigger. In a sense, he executes a series of procedures, but their dynamic interaction with the environment (range and target movement, particularly) involve constant iterations and modifications of what might otherwise be considered discrete events. At another level of complexity, a pilot landing an aircraft must continuously sense and compensate for changes in airspeed, altitude, angle of attack, carrier speed, wind velocity and direction, deck attitude and the effects of turbulence and sea state in controlling his aircraft. In each case, perceptual-motor learning involves psychological and learning processes that are difficult to assess. For purposes of analysis, measures of perceptual-motor performance have been developed, however, that reflect learning with sufficient validity to permit development and evaluation of alternate learning approaches.

The measurement of perceptual-motor skills is of special significance in the current system capability due to the extremely large proportion of time and money expended in training perceptual-motor skills in driver trainers, ship handling simulators, flight simulators, weapon system trainers and similar devices. Accurate and valid measures are essential in derivation of efficient training techniques and devices, and in development of techniques for utilization of automated training methods.

1.4.4.1.4 Judgmental Skills. Many of the skills involved in military operations are similar to perceptual-motor skills in their involvement with analysis, organization, perception and integration of current and stored data from a variety of sources. Their dynamics and intellectual nature, however, tend to make them less accessible to measurement, evaluation and training. Their measurement is critical, however, in the development of valid methods of training. Judgmental skills can be measured by comparison of trainee performance against performance of experienced personnel, or against judgmental criteria (standards) developed by computerized gaming.

In general, the major problem in measurement, recording and utilization of performance information is in the development of specific methods of data display and utilization consistent with the basic functions of the training system, with the learning principles involved and with the characteristics of personnel and the training situation under consideration. Usually, more data are available in a given training system than can be directly employed for training or for trainee and/or system evaluation. Data must be processed, however, to reflect learning rate, errors and system faults and to indicate required guidance and system modifications without requiring extensive interpretation.

Part of the solution to this problem is in identification during the training situation analysis of relevant performance data and criteria about the likely intercorrelations among performance parameters, learning and transfer. Another part is in experimental evaluation of specific data and combinations of data as predictors of learning and transfer of training. This requires that significant portions of the task to be trained be subjected to experimentation. Experimental designs should define measurable performance data and permit their correlation with each other and with measures of operational performance to establish valid performance criteria for predicting both learning and transfer of training. Performance data collected during experimentation should then be processed for four applications:

1) Employment as feedback to the trainee to facilitate learning.

2) Indications to the instructor concerning the progress of learning for his use in guiding the learning process.

3) Scoring of performance to reflect trainee progress toward training and operational performance criteria and to reflect training device validity.

4) Computer control of guidance and adaptive training regimes.

Further experimentation is required to evaluate the effectiveness of each measure and each data processing approach for its utility in its specific application.

1.4.4.2 Trainee Monitoring. Training management requires some degree of contact between the trainee's learning processes and the personnel responsible for training. The degree and mode of contact will vary with the type of task being trained, training methods employed and capabilities of both the training system and personnel who employ it. Ordinarily the assumption can be made that at least some aspects of trainee performance parallel his learning processes and, thus, trainee monitoring tends to involve the monitoring of performance of training tasks and subtasks having defined relationships to learning progress and transfer.

Three basic problems in performance monitoring require attention in the development of training devices. First, it is necessary to define the use to be made of the monitoring situation. Immediate guidance of training requires rapid processing and display of relevant performance parameters, and frequently the display of certain interactions among some parameters. The cross-country and approach recorders on Operational Flight Trainers are examples of simple, meaningful integrations of data generated in complex pilot performance. Use of performance data for system quality control and for grading and scoring requires less

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immediate data application and may require that data in different form. Second, the effectiveness of instructor evaluation and guidance depends very largely on the form of information provided, its relationship to the learning process, its timeliness and the extent to which it directly suggests the form of guidance required. A display may tell the instructor that a truck driver trainee is going 30 mph, for example. If it can also display the optimum speed range for the task being learned, it becomes a more effective device for guidance. If, further, it can simply display how much the driver should speed up or slow down to meet the current speed criterion, it may minimize nonessential instructor participation. At the lower level of display sophistication, the instructor must relate the displayed speed to his knowledge of speed appropriate to prevailing conditions; he must decide whether the trainee needs guidance at this time, and he must prepare and deliver an input that will facilitate learning. At the more sophisticated level, the instructor need only decide whether to provide guidance at this particular time or not.

Finally, it is necessary to determine the degree to which trainee monitoring can employ the data used by the trainee, and the degree to which the data must be processed or modified. In some training systems the instructor has ready access to information used by the trainee in learning. Occasionally, this information is of value to the instructor in anticipating trainee performance requirements and in evaluating his actions, but frequently the information used by the student is of little direct use to the instructor, who is most concerned with the task situation at a given time, the hierarchy of response alternatives open to the trainee and the effectiveness of the trainee's choice and execution of responses. Fromer and Horowitz (28) suggested that the instructor may not need the same kind of information as is needed by the student in an Operational Flight Trainer. The F-4E Weapon System Trainer exemplifies this concept in the display of engine status information to the instructor. Linear meters are used to display both the readings of the pilot's engine instruments, and the difference between the readings of the pilot's displays. Previously, duplicate instruments were placed at the instructor's station, which do not lend themselves to this type of comparative interpretation. One of the functions of the facility in question will be to devise and evaluate ways of organizing and providing essential monitoring information for specific devices and for training of specific tasks.

1.4.4.3 Training Situation Control. To be effective, each training session must progress through a series of steps: 1) the function of the session must be defined so that the trainee and the instructor know the task to be practiced, the criteria to be reached and the training approach to be employed; 2) the trainee must be permitted to practice relevant tasks or subtasks, and he must be provided guidance as appropriate: and 3) a score or series of scores must be generated to describe his performance during the session and his qualifications and/or needs for further training. Traditionally, these functions have been the responsibility of the instructor: he defines the functions to be performed, the criteria and the training approach; he monitors the trainee's performance during practice and provides comments about the meaning of errors and devises methods to reduce and/or eliminate them: at the end of the session the instructor debriefs the trainee and assigns scores that tell him the nature and quality of his status at that time, and prescribes remedial work and/or further training as appropriate.

Recent efforts have been effective in relieving the instructor of the responsibilities in this paradigm that are more mechanical than insightful, and in making more objective those responsibilities that have been, within the state of the art, unnecessarily subjective. As a result, training devices in development and anticipated for the future will make more appropriate use of unique capabilities of instructor personnel, device hardware and system programming. Making more appropriate use of training system components cannot occur in the present device development context. Expansion of training situation and task analysis efforts is required, and will contribute significantly to the design of effective devices, but an additional capability is required for experimental evaluation of means of allocating training control functions to components of the training systems. Specifically, the design of each training device must have available empirical data on the relative effectiveness of alternate allocations of four basic instructional functions:

1. Trainee Pre-Training Briefing - In some situations, the trainee can be briefed on the tasks, approaches, conditions and criteria appropriate to a given training session by a recording. This is particularly effective when the session is a fixed entity and the tasks to be trained are straightforward and well-defined. When training is necessarily more flexible, as in refresher training of experienced

personnel, it may be more effective and economical for the instructor to provide the briefing based on knowledge of the trainee's level of capability and specific training needs. The briefing may also include a demonstration of the task to be learned, which again may be best accomplished by a fixed program or an instructor.

2. Trainee Practice and Performance Feedback - During practice sessions, the trainee needs periodic information on the quality of his approach and performance. The training system itself needs performance information in order to continue to prescribe efficiently the conditions of practice and training. Performance data may be collected by the instructor or by the training device, providing each is appropriately programmed. Allocation of this function requires that data be collected in an experimental setting that represents crucial parts of the device utilization setting under consideration, to permit due account to be taken of the situation variables that influence the relative effectiveness of various approaches to trainee monitoring. The qualifications of the instructor, the level and complexity of the training given, the intrinsic value of the training and the ratio of availability of instructors at various levels of competence to the number of students to be trained are all significant influences on the mode of performance monitoring to be employed.

3. Guidance - Data collected on the quality of trainee performance are put to specific uses in advancing the training process. The guidance of learning consists in observations and analysis of performance, development of inferences about learning, formulation of approaches to improvement of performance and reduction of errors, and communication of these concepts to the trainee. In most cases, the guidance function requires more information than available from observations of immediate performance. Data are required concerning past performance in immediate and similar tasks and on relevant trainee characteristics to permit development of guidance concepts that are realistic for the specific trainee. For this reason, the guidance function has been traditionally assigned to expert instructors because of their ability to derive effective approaches from subjective analyses of trainee characteristics and past and current performance. Recent analyses (16) of complex operator tasks and of unique capabilities of training system computers has led to the development of computer programs capable of providing

effective guidance through analysis of relevant characteristics of the trainee and his performance. A basic requirement in supporting the allocation of guidance functions to computer programming is the development of capabilities for experimentally defining essential relationships among specific training tasks and trainee characteristics as reflected in basic capability scores and in task-relevant performance. Data are also required to reflect the relative effectiveness of possible approaches to organizing capability and performance data, and the effectiveness of providing guidance for the specific tasks and trainee populations involved.

4. Evaluation and Quality Control - Each training system must provide data and means of interpretation which permit evaluation of the learning process, not only for immediate guidance but to determine the qualifications of the trainee for advancing to the next training phase, and for eventually performing operational tasks toward which training is directed. Evaluation requires the determination of the specific criteria of successful performance in the operational system, which can be related to performance in training. It also requires development of a system of data analysis that permits valid inferences to be made about the quality of trainee knowledge and performance as it relates to the training approach employed. Performance criteria themselves are derived during training situation analysis, but they must continue to be defined as training system development progresses to account for the necessarily indefinite nature of early task and skill information and for changes in basic knowledge and skill requirements. Criteria must also be defined for each phase of training, frequently requiring some experience with the prototype training system and its associated devices. Experimental facilities for collecting data on learning performance in specific subtasks will drastically reduce the time required to implement the prototype training system, and the expense and time required in quality control to update prototype training system device and program designs. The efficiency with which valid allocations of evaluation functions can be made depends on the quality of the performance criteria available from the training situation analysis, from experience with the prototype system and from experiments conducted prior to training system employment. In general, successful evaluation programs can be written for training system computers when well-defined knowledges and skills are being trained but, when training is provided in the development of perceptions, judgments and team operations,

much evaluation must be performed by instructional personnel who have insight into the operational tasks being trained and experience with the development of the types of skills being trained. Evaluation schemes can be developed through experience but, again, experimentation prior to system employment can provide timely data with minimum disruption of the training process once it begins. It can also minimize expensive and inconvenient modifications to programs, devices and software to account for evaluation requirements discovered only after initial system utilization.

1.4.4.4 Computer-Management of Instruction. Training system computers can be programmed to perform functions that would otherwise be assigned to training system personnel (29,30,31, 32). They can also be programmed to perform training functions that would otherwise be impossible. Many performance measurement, recording, data analysis, organization and display functions that tend to enhance training effectiveness can only be performed by a high-speed computer. Many other essential functions ordinarily performed by the instructor or a device operator can also be handled by the computer -- not only to reduce workload demands on instructional personnel but, more important, to reduce demands on the qualifications of the instructor and to systematize functions that might otherwise be subjective and erratic. Another computer function in implementation of training is in organization and display of data required by the instructor to manage training operations. Computer programs can anticipate instructor requirements and provide training information in the most useful form and when needed.

While performance measurement, data analysis and display are essential training computer functions, the essence of computer assistance in instruction is in the establishment of a computer/trainee interface, whereby the computer program can respond meaningfully to immediate, variable trainee requirements for information, instruction, evaluation and guidance. Computer assistance can be provided in at least four different ways: 1) it can control the briefing of the student prior to a practice mission or in individual and classroom instruction; 2) it can demonstrate tasks to be practiced by the trainee, and effects on these tasks on relevant environmental or system variables; 3) it can monitor and critique performance by responding to trends and deviations from criteria with prerecorded comments; and 4) it can control the rate and mode of presentation and the complexity of individual training problems according to the immediate needs of the trainee.

The exploitation of computer capabilities in interacting with the trainee and his instructional requirements depends heavily on the ability to experimentally evaluate interaction modes and formats prior to final definition of computer programs, and prior to allocation of functions between the computer and instructional staff.

An initial problem in incorporating computer programs in an instructional sequence is in defining practical, meaningful segments of overall skill, and in defining intermediate performance criteria appropriate to each. Another is in evaluating alternate modes of presenting training information in each segment according to the circumstances under which training takes place. Given similar circumstances, it may be necessary for the instructor to perform functions in one simulator that might be performed by the computer in another. Variations in the requirements of specific training situations also make it necessary to define the kind, amount and timing of feedback, critique and guidance to be employed in a given training setting.

1.4.4.5 **Adaptive Training.** It has been traditional in military training to provide group training wherever possible and to minimize requirements for equipment, time and skilled instructional personnel. Formal individualized instruction has been given where necessary with informal, individual attention being given where possible, based on capabilities of individual instructors and training settings. From the point of view of the individual student, individualized instruction is frequently more efficient than group instruction, because it tends to account for the effects of differential capabilities, learning rates and learning modes, and requires less effort on the part of the student and in general less training time for the individual student. Unfortunately, individualized instruction has always required heavy involvement of skilled instructors at significant cost. Recent advances in computer-assisted instruction promise to make possible training system responsiveness to individual requirements and modes, reduce training time and increase efficiency (32,33,34,35).

The adaptation of a training situation to the specific requirements and capabilities of individual trainees and to groups of trainees requires that inferences concerning training approaches be drawn from available, relevant information about the individual or group. Recent research in adaptive training indicates that trainee qualifications and performance measures can be used to select learning approaches and training techniques to optimize rates (36). To be effective, adaptive training techniques must be capable of selecting among alternate training approaches and levels of task complexity, according to the specific capabilities of the trainee at a given point in the training process. Adaptation of the system to the trainee can involve the selection of an approach from among a catalog of alternates, or it can mean continuous manipulation of the content of training tasks. As a result, development of adaptive training programs for specific training devices and situations requires experimental acquisition of data relevant to that device or situation. Data are needed in two basic areas: 1) in defining relationships among specific qualification profiles, early learning performance and later performance in the training situation in question; and 2) in assessing the feasibility of various potential methods of manipulating the complexity of the training situation to adapt to individual trainee abilities.

The general principles underlying adaptive training techniques are not currently well enough established to generalize from one situation to another; the specificity of skills and of individual approaches to their development requires experimentation to permit available principles to be adapted to specific training contexts and to permit better and more broadly applicable principles to be defined. Of particular difficulty is the definition of methods of manipulating task variables in maintaining optimum performance levels and learning rates. This has been done in some adaptive programs through manipulation of task difficulty, but difficulty is an artifact accompanying variations in methods of presenting learning material, and is not usually directly relevant to the dynamics of task performance and learning. The basis of the adaptive training concept is the presentation of learning tasks that are not yet in the repertoire of the trainee, but that can be readily grasped by a trainee of given ability at a given time. Learning tasks must be segmented in meaningful fashion with respect to the learning processes they involve without altering or misrepresenting the essential characteristics of the overall task, and without requiring the trainee to learn a series of discrete, unrelated subtasks.

Specific tasks can be segmented and adjusted in a number of ways to match the learning capacity of the trainee at a given time. System dynamics may be varied, the trainee may be required to perform additional tasks, time constraints can be changed, augmented feedback information to the trainee can be degraded or delayed, or the criteria employed in initiating guidance and coaching programs can be varied with learning progress. Once task segments have been defined, programs must be prepared and validated on subjects with significantly different capabilities to facilitate automatic performance measurement and the initiation and adminstration of guidance, coaching and branching schemes in promoting efficient and effective learning.

Tasks can be segmented in a variety of ways, in the designation of part-tasks for training. Naylor (37), in a review of the literature on part-task training has shown that the relative efficacy of part- and whole-task learning appears to depend on the intelligence and the previous experience of the learner. Poulton (38), in Bilodeau's "Acquisition of Skill" points out that the value of task simplification, as an approach to task fractionation seems to depend largely on the nature of the task at hand. An experimental capability in the ETSS for evaluating various approaches to task fractionation is essential in view of the sensitivity of the approach to task characteristics. This will permit the definition of subtasks for adaptive training for a wide variety of tasks which have never been analyzed from this point of view. Current experiments in the application of adaptive training to jet aircraft and helicopter pilot tasks will have to be extrapolated eventually to a wide range of operator tasks.

Experiments are also required in deriving functional relationships among learner characteristics and specific approaches to task segmentation, and among learner characteristics and methods of providing performance feedback to the learner. Specific types of experiments in the area of adaptive training include:

1) Effects on transfer of training of specific approaches to the definition of part-tasks.

2) Task simplification and transfer.

3) Individual differences in transfer from part-task segments to the whole task.

4) Effects of augmented, delayed feedback on learning progress.

5) Effects on learning of variations in criteria for the initiation of coaching and guidance programs.

6) Effects of varying coaching methods; effects of individual differences on the utility of specific coaching methods.

1.4.5 Instructor Station Design. The training instructor and the personnel who administer, control, evaluate and guide the learning process are critical in assuring efficient, effective and economical training. Even in the most fully automated training context, the effect of training personnel is profound, if only in establishing trainee attitudes toward the operational task, the training system and the devices and programs employed. Where instructor participation is intimate, the effect is even greater; it requires as effective an interface between the instructor and the trainee as possible. The selection, design and arrangement of displays and controls at the device instructor's station is thus critical and, since these functions are highly specific to devices and systems, they will require experimentation in the identification, processing, arrangement and display of trainee performance information. Experimentation will also be required in the derivation of effective methods for the instructor to make meaningful inputs to training.

It will also be necessary to evaluate specific displays and controls for monitoring, programming, recording, playback and communications. Recent advances, particularly in display and programming technology, have provided new and improved methods of implementing instructional responsibilities. Cathode-ray-tube displays appear to facilitate the integration and display of data in more useful form than has previously been possible, and keyboards, light pens and other input devices appear to offer increased facility in inserting, monitoring and modifying programs. Each has its own limitations, however, as well as its own unique capabilities.

Special problems of readability and manipulability accompanying each design as it relates to each utilization mode and situation anticipated for it must be resolved in making optimum use of advanced, novel techniques. As a result, capabilities must be available for evaluating effects of alternate hardware approaches on instructional functions.

1.5 FUNCTIONAL REQUIREMENTS FOR THE EXPERIMENTAL TRAINING-SIMULATION SYSTEM. The support of experimentation in the five device design areas discussed in paragraph 1.4, the Trainee Station, the Fidelity of System Dynamics, External Environmental Fidelity, Instructional Management and Instructor Station Design requires an extensive laboratory capability. Further, this capability must exhibit a high degree of flexibility to support experiments related to the range of operational systems and training device concepts within the responsibility of the Human Factors Laboratory.

The Experimental Training-Simulation System must be able to perform three separate but related functions. First, it must provide for the representation of the system control and display hardware forming the operator/system, and the instructor/device interfaces in a variety of systems and training devices. Second, it must represent those systems and devices in various degrees of fidelity, through the activation of interface equipment and through the representation of essential elements of the system environment. Finally, the ETSS must provide a capability for the design, control, monitoring and evaluation of a large number of experiments in the value of various approaches to training device design and utilization. Phase II of the study was designed to reconcile these relatively extensive functional requirements with an economical, flexible organization of state-of-the-art equipment and techniques.

Initial attempts at organizing hardware approaches to the ETSS experiment requirements suggested the need for a "simulator of simulators." The implications of simulating each of the variety of systems identified in Phase I were derived from a cursory analysis of essential system characteristics. It was found that, for purposes of training experimentation, a great deal of commonality exists among the various systems and operator tasks considered. For example, a tank driver manipulates similar controls to those used by an air cushion vehicle operator, he interprets displays which are similar to some of those encountered in aircraft cockpits, and even the aircraft pilot and the submarine diving officer deal with similar problems using similar equipment. The learning problems associated with a wide variety of systems also reveal many common elements for experimental analysis. Both a radar operator and a rifleman, for example, must be trained to recognize complex visual patterns; even though each is generated in a different manner in the real world, each requires training in complex perceptual organizations. Further, even these diverse skills involve the learning of facts, procedures and motor skills which are all susceptible to similar training approaches.

As a result of the observed commonality of learning problems among the military systems studies, ETSS equipment requirements were derived in response to learning problems, rather than in response to specific military system characteristics. These learning problems imply hardware and software requirements in five equipment "types", which were considered in Phase II of the study; these are discussed below.

1) Trainee Station Design. This requirement relates to four separate learning variables which, in turn, imply specific types of equipment.

a) Knowledges. The common methods used for the development of knowledge are the use of printed matter and audio-visual equipment. This study concentrated on techniques for the design and use of the latter approach, due in part to the utility of audio-visual equipment in other areas of experimentation. The vast amount of learning at this level, in relation to almost all military systems necessitates a high level of attention. The capabilities within this area have been organized around the concept of Training Aids Research.

b) Perceptual Skills. This area of experimental capability concerns the development of skill in organizing complex patterns of information through the use of instruments or visual displays. A major portion of the training in this area is associated with radar and sonar type displays. Accordingly, a major portion of the equipment was designated with these capabilities in mind. This area, called the

Sensor Interpretation area, also encompasses experimentation in the development of procedural skills, since each type of indicator and its operation necessitates some kind of more or less complex action on the part of the trainee.

c) Psychomotor Skills. Experiments in this category require an operating systems simulator. Equipment in this area must be able to provide both the stimulus patterns and output capabilities associated with psychomotor experimentation. All cues will be provided to the extent feasible, to assure that the effects on psychomotor skills of such things as vehicle dynamics, the environment and the available instrumentation can then be evaluated based on an operational situation instead of in terms of individual independent variables.

d) Judgmental Skills. Experimentation in this area requires relatively extensive information displays, and capabilities for trainee responses reflecting the decision process. An example of this type of equipment is that found in either a combat information center or an ASW aircraft. In the former, display boards and communications equipment are required. In the latter, sonar, MAD and similar displays and associated equipment are necessary. This area, Tactical Decisionmaking, will be capable of formulating experiments in situations of these types.

2) Dynamic Fidelity. The software associated with the computational system will be flexible and easily alterable to permit experiments on the effects of varying the fidelity of the simulated system. In addition, the equipment which informs the subject of essential task information, i.e., instrumentation, will be capable of representing a wide range of dynamic fidelity.

3) Environmental Fidelity. Equipment flexibility must be provided with respect to perception of the environment. A major function of the ETSS is in representing the motion, visual and aural cues available in the environment of a variety of military systems.

4) Instructional Management. The capability in this area will permit experimentation in the control of simulation and other training situations. This control will be

implemented by software capable of problem setup, performance measurement and feedback control.

5) Instructor Station Design. The equipment designed for this area includes multi-purpose control and display devices. The questions to be answered in this area relate to the type of information needed as well as the most effective method of presenting that information, in the control, monitoring, guidance and evaluation of trainee performance.

2. PHASE II

The Phase II analysis placed major emphasis on examining available equipment for hardware capable of meeting the requirements for human factors experimentation defined in Phase I. In the absence of available equipment capable of supporting specific experiment requirements, design studies were performed to develop specifications for hardware possessing the required capabilities.

The results are presented within each of the seven principal areas of investigation and analysis:

a. ETSS Research & Development Areas - The Experimental Training Simulation System will permit experimentation in four general areas of training device design, i.e., training aids design, sensor interpretation, tactical decision-making, and the simulation of complex integrated systems (par. 2.1).

b. Equipment Requirements - Operational areas were analyzed to determine the simulation hardware requirements best suited to the solution of human factors design problems (par. 2.2).

c. Monitoring and Control Requirements - Performance monitoring and control requirements for the ETSS were established to facilitate experiment setup, control, monitoring and evaluation function (par. 2.3).

d. Custom Hardware - Preliminary design studies were performed to identify equipment that could perform multiple functions and to define requirements for special purpose equipment (par. 2.4).

e. Data Flow - The flow of data through the system was optimized with respect to the variety of experiments to be performed and the anticipated modes of system utilization (par. 2.5).

f. Analysis of the Experimenter's Station - A human factors analysis of the configuration selected was performed and a rationale is presented (par. 2.6).

g. ETSS Data Support Requirements - Provisions were made for ready access to past and continuing research data, in support of ETSS experiments (par. 2.7).

Table 1 (Page 74) summarizes the knowledges and skills required by operators of military systems and the types of devices typically used for training. The devices listed in the table were evaluated for each task category as a point of departure in identifying training devices with the broadest, most effective application to training of the respective skills. The functional requirements derived in the Phase I study further defined hardware concepts for support of training device studies and are reiterated herein as ETSS experimental areas:

a. The trainee station - Capability to quickly reconfigure trainee panels to various fidelity levels (from paste-ups to working instruments).

b. Fidelity of the system dynamics - Capability to alter the fidelity of computed variables within the simulation model.

c. External environmental fidelity - Capability to vary the fidelity of all stimuli encountered by the trainee.

d. Instructional management - Capability to vary the method of controlling the training situation (from the simplest to the most complex training device).

e. Instructor station design - Capability to vary the configuration of simulated instructor station components, features and arrangements, including use of multipurpose display and control devices.

2.1 RESEARCH & DEVELOPMENT AREAS. Four specific areas of research and development were found to be required for an Experimental Training Simulation System which could satisfy the requirements identified in Phase I. These areas relate to the tasks and device concepts identified in Table 1. As shown in Table 1, five military task categories were identified. Examination of each task category and each task element, (knowledge and skills) from the point of view of typical hardware used in training, resulted in the translation of the five psychological categories to four ETSS research and development areas: training aids, sensors, tactical decision-making and system research. These four areas evolved as a result of:

a. The types of controls and displays pertinent to the operational areas.

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TABLE 1. TRAINING IMPLICATIONS OF OPERATOR TASKS

TASK CATEGORY	POTENTIAL TEACHING APPROACHES	TYPICAL DEVICES
1.0 KNOWLEDGES:	1.0 KNOWLEDGES:	1.0
1.1 System Mission Functions 1.2 Nature and Effects of the Mission Environment 1.3 System Design Characteristics 1.4 System Functional Characteristics 1.5 Normal Operating Procedures 1.6 Alternate and Emergency Operating Procedures 1.7 Standing Operating Procedures 1.8 Communications Procedures	Acquisition of data and the development of concepts concerning the system, its mission and its operating environment through exposure to factual information and to representation of the system, mission and environment.	Transparencies Animated transparencies Records, films, filmstrips Models, cutaways Maps, charts, photos Texts, manuals Programmed texts Teaching machines Classroom responder systems Mockups, Familiarization trainers.
2.0 PERCEPTUAL SKILLS	2.0 PERCEPTUAL SKILLS	2.0
2.1 Diagnosis of System Status Displays: Interpretation of system visual, aural and tactile displays in diagnosing the capacity of the system and its elements to perform specific system mission functions. Essential Task Elements: (1) Knowledge of the system mission and environment. (2) Knowledge of the correlation of system status indicators with system mission capabilities. (3) Perception of the status implications of various patterns of information. (4) Identification of course of action consistent with system mission requirements and system status.	a. Exposure to printed, photographic and/or audio representations of significant information patterns. b. Exposure to operational system, sensor and environmental data. c. Programmed or unprogrammed guidance in identification of significant information patterns. d. Programmed or unprogrammed guidance in analysis of the effects of system and environmental parameters on information content of indicators of system and environmental status. e. Simulation of the interactions of system elements under typical circumstances of element condition, capability and status, environmental conditions, mission requirements and system operator inputs.	Cockpit Procedures Trainers Instrument Trainers Celestial Navigation Trainers Submarine Diving Trainers Submarine Control Trainers Sonar, Radar Trainers Photo Interpretation Trainers Tactical, Maneuvering and Attack Trainers Amphibious Operations Trainer Target Simulators Records, Films, Terrain Models

2.2 Sensor Interpretation:

Interpretation and organization of information provided by the special sensor systems, in the detection of targets, obstacles and tactical conditions, and in the selection of functional courses of action. Sensor systems would include: 1) Airborne, ground, traffic control, portable, side looking and doppler radar; 2) Sonar visual and aural displays; 3) Magnetic anomaly displays; 4) Infrared imagery and photography; 5) Black and white and color still and motion picture photography; 6) Teletype, aural and visual communications and intelligence data; 7) Low light level television; 8) Image intensifier displays; 9) Electronic countermeasures displays; 10) Closed-circuit television; 11) Optical aids to vision; 12) Unaided observation, ground-to-ground, ground-to-air, and air-to-ground.

Essential Task Elements: 1) Procedures required in sensor adjustment; 2) Knowledge of sensor characteristics and capabilities; 3) Knowledge of correlation of target and environmental parameters with sensor display characteristics; 4) Perception of signals in noise; 5) Perception of target and environmental effects on display characteristics.

TABLE 1. TRAINING IMPLICATIONS OF OPERATOR TASKS (CONT'D)

TASK CATEGORY	POTENTIAL TEACHING APPROACHES	TYPICAL DEVICES
2.3 Environmental Evaluation: Utilization of data obtained through direct visual, kinesthetic, auditory and tactile contact with the system environment, in the control of system mission functions. Essential Task Elements: (1) Visual Tasks: (a) Unaided and optically aided detection, identification and acquisition of targets, ground-to-ground, ground-to-air and air-to-ground; (b) Vehicle control through interpretation of visual cues to position, attitude, path, velocity and heading; (c) Control of system elements through interpretation of visual cues to relative portions and motions of elements and the physical and tactical environment. (2) Proprioceptive Tasks(a) Perception and interpretation of motion and vibrational cues to system equipment status and condition; (b) Perception and utilization of cues to system motion, in system control. (3) Auditory Tasks: (a) Perception of system and system equipment condition through analysis of system sounds; (b) Utilization of system and environmental sounds in system and subsystem control.		
3.0 PROCEDURAL SKILLS Selection and execution of sequences of discrete control actions, at the proper time and in the correct order. Essential Task Elements: (1) Knowledge of the procedure required by the mission. (2) Knowledge of system capabilities within the mission context. (3) Selection of appropriate normal, alternate or emergency procedures. (4) Execution of procedure in proper sequence and time. (5) Observation of the effects of the procedure on the system and/or mission. (6) Modification of the procedure as required to achieve the required mission effect.	3.0 PROCEDURAL SKILLS a. Mockups, photographs and non-activated familiarization trainers. b. Simulated and operational communication systems. c. Tactical with simulated operator stations in which appropriate feedback from student response is provided. d. Pre-programmed practice with simulated operator's station, suitably activated. e. Pre-programmed practice with simulated operator's station, suitably activated, with augmented feedback and/or guidance programs. f. Pre-programmed practice in operational systems, with augmented feedback and guidance programs.	3.0 Cockpit Procedures Trainer Operator Position Simulator Periscope Trainers Operational Flight Trainers Operating Mockups Turret Trainers Communications Trainers Teaching Machines
4.0 PERCEPTUAL-MOTOR SKILLS Continuous modification of one or more system control outputs, as a function of the perception of discrepancies between actual and required system performance. Essential Task Elements: (1) Knowledge of system performance capabilities. (2) Knowledge of system status. (3) Knowledge of system functional requirements. (4) Perception of discrepancies between actual and required system outputs.	4.0 PERCEPTUAL-MOTOR SKILLS a. Practice in control of individual system parameters, using part-task trainers. b. Pre-programmed practice in control of individual system parameters using part-task trainers having augmented operator feedback and guidance programs. c. Pre-programmed practice in the control of combinations of system parameters, using part-task and/or operator position trainers having augmented feedback programs and automatic measurement, evaluation and guidance programs.	4.0 Part-Task Trainers Procedures Trainers Operator Position Simulators; Driver Trainers Weapon System Simulators; Gunnery Trainers Mission Simulators Instrument Trainers, Navigation Trainers Radar, Sonar, MAD, ECM Trainers

TABLE 1. TRAINING IMPLICATIONS OF OPERATOR TASKS (CONT'D)

TASK CATEGORY	POTENTIAL TEACHING APPROACHES	TYPICAL DEVICES
(5) Control of system outputs to null discrepancies between actual and desired output.	d. Practice in coordinated control of system parameters, among more than one system control station.	
(6) Continuous tracking of system environmental parameters.	e. Pre-programmed practice in the coordinated control of system parameters, among more than one system control station, with augmented feedback, and with automatic measurement, evaluation and guidance programs, employing simulators representing system elements having significance for the individual and group tasks being trained.	
(7) Simultaneous tracking of multiple system environmental parameters.		
5.0 **JUDGMENTAL SKILLS**	5.0 **JUDGMENTAL SKILLS**	5.0
Selection from among alternate courses of action in the fulfillment of a mission functional requirement, thru analysis of the mission, the environment, the system and the probability of success of each alternative.	a. Analysis of symbolic representation of the system, system and subsystem capabilities and current status, the mission functions required of the system and of the mission environment in the development of appropriate courses of action.	Mission Simulators Tactical Trainers ASW Tactical Trainers Tactical Gameboards Maneuvering Tactics Trainers Command Post Trainers
Essential Task Elements:		
(1) Knowledge of system mission.	b. Selection and execution of alternate courses of action in a representation of those aspects of the system having significance for the judgmental skills being trained.	
(2) Knowledge of system functional requirements.		
(3) Knowledge of system mission environment.	c. On-the-job training in the system and system environment.	
(4) Knowledge of system and subsystem capabilities and current status.		
(5) Knowledge of the effects of the mission environment on system and subsystem capabilities.		
(6) Perception of interactions among subsystems and system elements.		
(7) Prediction of interaction modes of system elements during the system mission, within each alternate course of action.		
(8) Estimation of probabilities of success of each alternative course of action, within the mission function/environment/system status context.		
(9) Observation of system/mission interactions, diagnosis of system functional capabilities and modification of system outputs as required.		

b. The requirement for conduct of R&D with respect to the task categories listed in Table 1.(Page 74)

c. Fulfillment of the experimental requirements imposed by the experimental areas. Of particular importance within this group were the task categories. It was assumed that since these are essential basic skills transcending all aspects of human learning that the ETSS must have relevant capability in these areas. It is well understood that it is possible to achieve training in the task category "knowledge" in the context of a mission simulator. However, since part of the function of NTDC involves specifying devices which are used only for knowledge transfer, experiments of this nature performed in a high fidelity simulator, no matter how degraded the math models are, would be of little value. Thus, a separate structure entitled "Training Aids" is specified for the ETSS. This same analogy applies to the other task categories. Therefore, the following relationship between task categories and research and development areas is established.

TASK CATEGORY	R&D AREA
1. Perceptual-motor	Systems
2. Perceptual	Sensor
3. Knowledge	Training Aids
4. Procedural	Tactical Decision-Making
5. Judgmental	

The equipment requirements for the ETSS were examined in relation to these four areas. However, since flexibility was the keynote in equipment selection, many devices are used in more than one R&D area.

2.1.1 Training Aids Research & Development. This area is concerned with the experimental capability in knowledge transfer, and concerns computer-aided instruction, audio-visual instructional devices, cutaways, models and the like. Almost all systems involving a human operator include training programs incorporating training aids of some type for early phases of instruction. Thus, the ETSS must have this capability for experimentation.

2.1.2 Sensor Research & Development. A large portion of the training for which the Naval Training Device Center is responsible is associated with sensor interpretation. Since this is a significant and complex area, it was determined that the ETSS sensor capability should be flexible to permit the simulation of various kinds and types of sensor indicators and input systems such as radar and sonar.

2.1.3 Tactical Decision-Making Research & Development. Many of the tasks in larger systems -- naval ships, ASW aircraft and submarines -- require operators who monitor consoles, communications and other displays, making tactical decisions based upon the data presented. This capability relates directly to the task category of judgmental skills. Thus, the ETSS must be capable of performing experiments in this area, particularly in light of the increasing relevance of this area to military systems and the increased complexity of systems, which pose significant training problems.

2.1.4 Systems Research & Development. This capability area transcends all task categories in Table 1 (Page 74). Systems research is defined here as a complete representation for purposes of training, of an operational system such as the F4J Weapon System Trainer. The ETSS systems research capability must include versatility in the system simulation area. It must include flexibility in simulation fidelity and instrumentation at the various stations, vehicular representation including vehicular control and representation of other systems. It must also permit simulation of many types of vehicular and other total systems to the extent required for valid experimentation.

2.2 EQUIPMENT REQUIREMENTS. The specific areas of NTDC responsibility were analyzed to define requirements for ETSS equipment. These areas refer to the specific military equipment for which NTDC has training device responsibility, e.g. tank trainers. Thus, the types of equipment considered and subsequently selected for the ETSS are derived from this review and the psychological implication imposed from Table 1.

2.2.1 Audio-Visual Equipment. Analysis of ETSS audio-visual equipment needs indicated the following set of required capabilities:

a. Presentation of audio information only, with or without subject response, together with linear or adaptive sequencing.

b. Still or motion picture visual only, with or without subject response and linear or adaptive sequencing.

c. Still and motion picture visual, with audio, with or without subject response and linear or adaptive programming.

Table 2 (Page 80) is a representative list of equipment surveyed, and indicates the features that each provides. It was found that many devices have multiple features, yet none satisfies all requirements. The unit meeting the greatest number of requirements is the Modec device. It is also the most expensive item -- about $15,000 -- but does not provide an adaptive sequencing capability.

2.2.2 Computer-Assisted Equipment. This capability utilizes electronic displays to present information in two distinct formats: 1) alphanumeric text, and 2) pictorial concepts, with animation and associated text as required. Alphanumeric text displays are necessary to facilitate adaptive learning experimentation. Three techniques for alphanumeric text display were investigated to fulfill the requirement. The first technique involved use of a standard television or raster scan cathode-ray tube (CRT). The variety of possible updating speed ranges and screen character capacity are sufficiently flexible that no specific requirement need be made at this time. Although it is recommended that at least 2000 characters and an update rate of at least 60K characters per second be a minimum, for example, the number of displayed characters ranges from 384 to 4080*, and the input/output rates (based on time to rewrite an entire CRT page) vary from 15 to more than 300,000 characters per second.

The second technique investigated uses the alphanumeric capability of Type 339 displays currently in the Human Factors Laboratory. The screen has a capacity of 3672 characters (~1600 flicker-free) and a writing speed of about 50 microseconds per character, which enables the screen to be completely updated in about 0.2 seconds.

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* "CRT Displays," Modern Data, September 1968.

TABLE 2. AUDIO-VISUAL DEVICES AND PARAMETERS

DEVICE	STILL	MOTION	AUDIO	INTEGRATED OPERATION	RESPONDER	ADAPTIVE	COMPUTER INPUT
Slate (ITC)	X		X		X	X	
Audio Scan	X		X	X			
Audio Vision	X		X		X	X	
Modec	X		X		X	X	X
Dadator	X		X		X	X	
Mini-book	X				X	X	
Autotutor	X				X	X	
Dorsett	X		X		X		
CBS Viewlex	X		X	X			
Visual Inst. System	X	X	X			Audio only	
Gemco	X	X	X		X		

X's indicate features of device listed.

The third technique investigated uses television pictures of the associated text; each instructional program is put on video tape and each frame or page is addressable. A page of information is presented to the subject along with the question, the page being a replayed video image from the data stored on the video tape. The Ampex Videofile* system can fulfill this function.

The second format for display of computer-associated information involves pictorial concepts, often animated, with associated text in the form of questions. The previously mentioned Type 339 CRT display also provides this format capability.

There are several additional methods to achieve this capability; e.g. RAND tablet, touch sensitive displays, etc. These methods, however, are typically not as flexible as the electronic CRT display. Resolution is also limited. Therefore, the CRT's were considered the only acceptable methods of achieving this function.

2.2.3 Panel Mockups. The complexity of modern military training instrumentation and equipment demands sophisticated research and experimentation to obtain optimum designs for instructor control stations. Although affected by the complexity of various systems, the ETSS control station must be designed to minimize differences in instructor actions. These actions may be influenced by instructor training, size, number and complexity of instrumentation and by the color and position of console components. The account for these varying parameters in the ETSS, a system to simulate many different panel configurations was defined.

A preliminary investigation and an evaluation of representative operator and experimenter control systems established the following requirements for a panel mockup system:

a. An inventory of instrumentation capable of representing various panel configurations.

b. Capability of the system to function with a variety of panel configurations.

c. Modular design.

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* Registered Trademark of the Ampex Corporation

d. Input monitoring capability.

e. Logic circuitry capable of accommodating a variety of panel instrumentation.

f. Ease of implementation into a functional system.

g. Flexible

h. Expandable

i. Compatible electronic interconnections.

To implement the use of working mockups of various panels for experimentation with variations in data, patterns, fidelity, color codes, etc., the following associated equipment and facilities were determined to be necessary. (Figure 2, Page 83).

a. Subject (trainee) Station
b. Experimenter's Station
c. Computer and software
d. Model/Fabrication Facility.

In order to determine the required number and types of computer interface channels -- analog to digital (A/D), digital to analog (D/A), for example -- an analysis of the F4E and F111D cockpits and instructor consoles was performed. The analysis also permitted classification of controls and displays as either standard or nonstandard: standard devices include toggle switches, pushbutton switches, digital readouts and other devices that perform a straightforward simple function; nonstandard devices are specialized, usually multi-function, control and displays. An aircraft artificial horizon indicator is an example of the latter. Table 3 (Page 84) is a summary of maximum instrumentation and computer interface types present in the F4E and F111D simulator stations. The quantities appearing in Table 3 were derived by tabulating the quantity of each type device in the panel of each simulator. The maximum number found was then established as the ETSS Panel Mockup requirement.

A detailed discussion of Panel Mockup design requirements is presented in Appendix L.

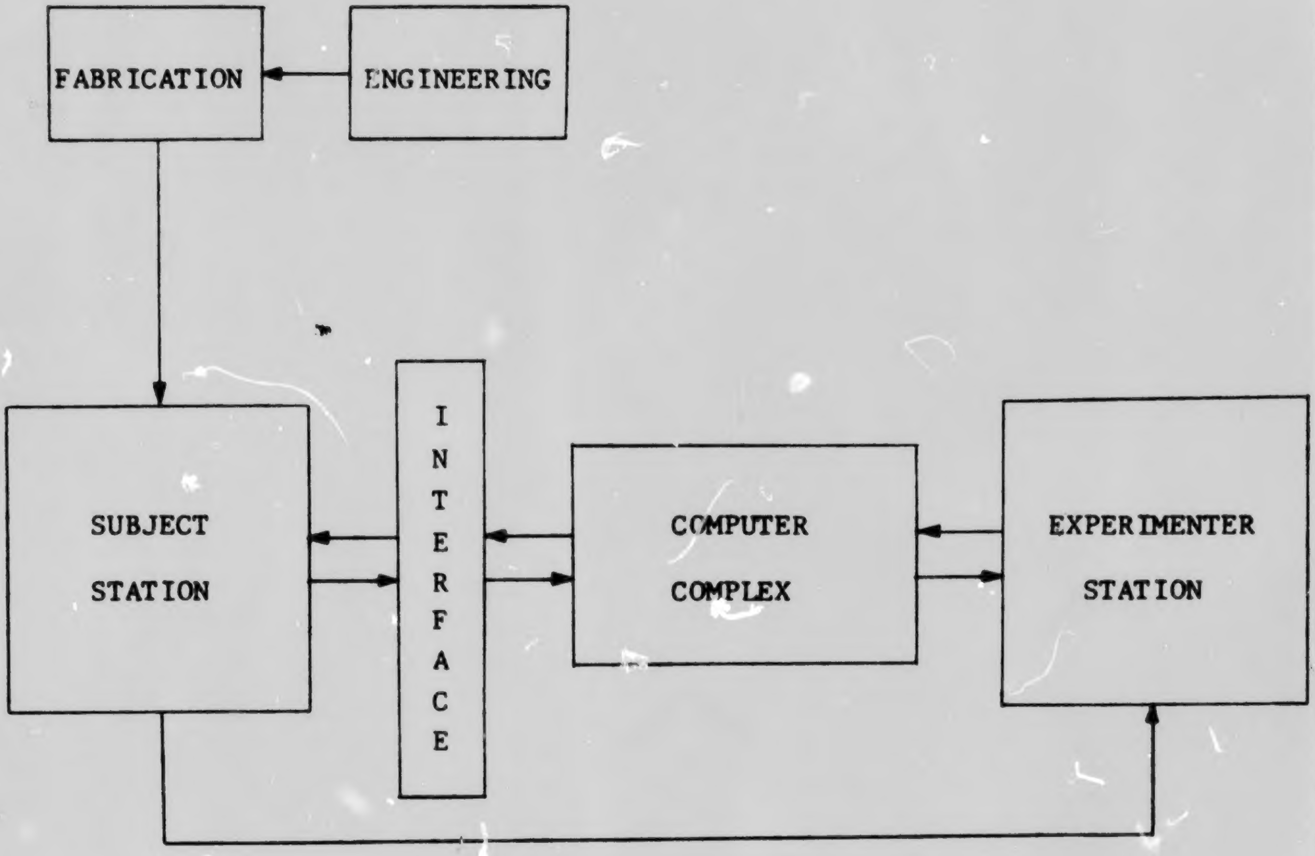
FABRICATION
ENGINEERING
SUBJECT STATION
INTERFACE
COMPUTER COMPLEX
EXPERIMENTER STATION

Figure 2. Required Facilities

TABLE 3. INSTRUMENTATION REQUIREMENTS

INSTRUMENT NAME	FUNCTION	INPUT/OUTPUT TYPE	NO. REQ'D
Twist Lite	Alternate Action	Discrete Output	7
Digital Switch	Selector	Discrete Input	5
Round, Dial, Skirted	Rotary Potentiometer	Analog to Digital	9
Digital Readout	Projection Display	Digital Output	11
Bina-View	Rear Projection	Digital Output	10
Status Display	Indicator Light	Digital Output	10
Strip Meter	Analog Readout	Digital to Analog	8
Pushbutton	Two-Position Switch, 5 amp	Digital Input	20
Toggle	Position Switch, 5 amp	Digital Input	20
Rotary	Position Switch	Digital Input	10
Jacks	Headphone, etc.	---	4

2.2.4 Vehicle Simulation Equipment. It was established in Phase I that the ETSS must allow experimentation in training device design features related to training environment and fidelity of device dynamics. During a typical training session, in an operational vehicle, the environment around the subject may be extremely complex. Typically, the training environment may be comprised of kinesthetic, visual, aural, touch and feel, olfactory and ambient atmospheric stimuli. Modern simulators, by including these stimuli create a training environment that contributes to transfer, by providing the stimuli by which complex responses are learned. Requirements for the simulation of visual, proprioceptive, and aural cues have resulted in a simulator technology capable of meeting a wide variety of environmental simulation needs. A concise resume of some of these capabilities is contained in the AIAA Visual and Motion Simulation Technology Conference, 1970.

Providing the ETSS with the capability of simulating aural, kinesthetic and visual cues extends the scope of training research to all fields of training device design within the cognizance of the Naval Training Device Center. These training device requirements include airborne, land, and marine vehicles and various devices such as weapon firing trainers, emergency escape trainers and other specialized training devices. The simulation requirements relate to the characteristics of these systems and are discussed in the following paragraphs. A commentary on the simulation techniques employed for the three primary sensory cues is also included.

2.2.4.1 Motion. The requirement for a motion base within a training complex arises from the extensive information transfer occurring in the man-device system by way of man's ability to respond to various types of motion. There are various schools of thought about the type of motion, the portion of a motion maneuver and the magnitude of motion cue that contribute most toward information transfer between subject and simulated system. The relative importance of motion within the man-device system varies with task loading and is interrelated with other sensory perceptions, notably visual inputs.

Appendix I discusses the concept of motion simulation, the philosophy of motion cue presentation and the relative merits of synergistic versus cascaded motion systems.

An ideal motion system would reproduce the vehicle accelerations, velocities and excursions in all degrees of freedom associated with the operational vehicle. However, due to mechanical and spatial constraints, these dynamic characteristics have to be restricted to reasonable values. This causes a dilemma, as a result of the psychological perception of proprioceptive cues; little evidence exists as to the nature of the ideal parameters for a motion system for the simulation of a given vehicle. The recommendations of the ETSS will be determined by an analysis of characteristics of a number of vehicle types and will allow sufficient freedom of choice so that optimum motion characteristics may be chosen for the vehicle being investigated.

2.2.4.2 Vision. Emphasis on visual simulation has long existed but has increased in recent years with the advent of more complex vehicles and systems, and with new requirements to operate vehicles under extreme conditions of low visibility. It is not only difficult but also may be dangerous to train in operational systems. The problem is further compounded by the fact that operational training must wait for a combination of desired weather and availability of training area. While the simulation industry has been striving to overcome the visual simulation problem, other facets of the ground-based simulator have been made to perform with excellent fidelity due to the application of large-scale digital computers. The net result is that simulation of sensory cues, notably visual cues, lags behind the technology of the ground-based simulator.

In general, requirements for realistic visual simulation for each operator task could be satisfied by a system that includes the following capabilities:

a. Unlimited freedom of maneuver - the ideal system should have an unlimited capability to simulate vehicle motions in all degrees of freedom with respect to fixed reference frame in which the vehicle operates.

b. High quality presentation - the image quality displayed to the subject should contain real-world fidelity in natural color over the entire spectrum of tasks involved in the subject-device combination.

c. Field of View - the field of view available to the subject should be representative of the real-world situation.

Appendix J presents a brief summary of approaches that have been used, and those that are being investigated for satisfying visual simulation requirements. Many visual systems have been built that hint at one or more of these features but none have so far provided a totally acceptable solution to the visual simulation problem.

2.2.4.3 Audition. Aural simulation requirements, under certain conditions, are as important as the motion and visual requirements. The capability for aural synthesis has developed in the past few years to a high level of sophistication. In part, this has been due to the requirements of sophisticated ASW simulators and the need to have better aural simulation in aircraft simulators. As a result, a capability exists that allows a large range of sounds to be simulated using a relatively compact sound synthesis system.

Appendix K describes some of the techniques that may be used for sound generation together with their limitations. An ideal aural simulation capability should be able to generate the sounds heard by the subject at the correct aural intensity, the correct angular separation and with minimum distortion (intermodulation and amplitude distortion). Before a sound system can be simulated through use of recordings or by synthesis, it is important that an analysis of sounds be performed. Analysis must concern both the psychological and quantitative evaluation of the specific sound. Current sound analysis capabilities are extremely sophisticated, allowing an almost unlimited degree of responsiveness to aural simulation requirements.

2.2.4.4 Vehicle Characteristics. The ETSS will be used in experiments involving a wide variety of vehicles. Aural, kinesthetic and visual requirements are directly related to the general characteristics of airborne vehicles, ground-based vehicles and maritime vehicles.

2.2.4.4.1 Airborne Vehicles. Airborne vehicles are generally either fixed-wing or rotor craft. The vehicles included in this category encompass a tremendous performance range when related to simulator engineering. In general, these vehicles have four distinct operating regimes, each one with its unique simulation requirements. These regimes may be classified as ground handling operations, takeoff and landing procedures, conventional flight and abnormal flight. Appendix F presents a discussion of the characteristic vehicle dynamics associated with each of these regimes.

2.2.4.4.2 Marine Vehicles. Vehicles falling into this category are surface ships, and submersibles. These vessels operate in or around an interface comprised of the atmosphere-ocean boundaries. As a result wave action, buoyancy and wind action interact in determining the motion of a maritime vessel. A discussion of the kinesthetic and visual characteristics of maritime vehicles as they relate to the ETSS is presented in Appendix G.

2.2.4.4.3 Ground Based Vehicles. Vehicles in this classification encompass cars, buses, trucks, trains, cross-country vehicles and air-cushion vehicles. The performance range of ground-based vehicles is reduced as compared to airborne vehicles. In particular, the velocity and altitude components are very much reduced. However, two factors tend to complicate the simulation of terrain-based vehicles. First, the terrain traversed is random in nature and no specific data describing terrain effects are available for use in vehicle simulators. Second, since all these vehicles operate in the ground effect area of aerodynamics, the equations of motion are extremely difficult to define as the vehicle velocity increases to a point where aerodynamic forces are significant.

Appendix E illustrates a typical set of equations for an automobile operating in a controlled environment. It serves to illustrate the complexity of the equations in the absence of terrain variations and aerodynamic forces.

The characteristics of ground-based vehicles are discussed in Appendix H as they relate to the kinesthetic and visual requirements of the simulation capability. The effects of random terrain are briefly discussed from the human engineering aspects.

As an example of a ground vehicle simulator, Appendix D presents an extract from an automobile simulation specification, demonstrating the difficult nature of ground-based vehicle simulation.

2.2.5 Sensor Displays. Sensor displays, as used in military devices, provide capabilities for active and passive weapon aiming and navigation. Specific sensor display requirements, characteristics, frequency, scan rate, etc., are peculiar to respective operational equipment -- sonar, air-to-air attack radar, shipboard navigation set, etc. The ETSS sensor display experimental capability, therefore, must provide as many of the required (and potential) display characteristics of operational equipment as possible for maximum flexibility and utilization. Display of sensor information can be provided by two techniques:

a. Straightforward repeat of all indicators.

b. Graphic displays that permit presentation of multiple indicators in a comprehensive format.

The first technique is totally impractical for cost-effective reasons; the second offers the most flexible, cost-effective solution.

The type 339 graphic display is most practical for ETSS purposes. It provides a 1024 x 1024 dot matrix 9-3/8 inches square. Its 30 Hz refresh rate (to prevent flicker) and 35 microsecond write time for each point (assuming random point) permit plotting of about 800 points. While this does not provide a very detailed image, particularly of coastlines, meaningful although not quite as detailed information can be provided by using vectors. Since the display points are 0.009 inches apart, 800 points provide a line about 7 inches long at scale 0 (every point). In vector mode, a 7-inch line can be drawn in 0.7 milliseconds.

Representation of background clutter is also a problem with the graphic display approach. Clutter can be generated by the variable dot density method used to print pictures in newspapers, but this requires large numbers of dots. For example, a one-inch-diameter circle contains 3700 dots. Using a 20 percent intensification factor to generate a sea scatter pattern on a shipboard radar would consume all the writing capability of the 339. Thus the 339 can be used, but in fairly low density situations.

The Type 339 display can be used for several types of experimentation. These are simple ones dealing with low information content electronic indicators of the type associated with certain radars and sonars. These are sufficient to achieve the intent of the ETSS. Other visual detection indicators, such as infrared and low light level television (LLTV) cannot be simulated effectively using the standard 339 display system. It is possible that these latter indicators may be simulated by using the 339 display system in conjunction with specialized display heads, or by the use of operational equipment tied into the simulation system.

2.2.6 Computer Requirements. The ETSS computation function will be performed by a digital computer complex similar in nature to the XDS Sigma 5; the complex will include the central processor unit (CPU), appropriate peripheral equipment and real-time interface. Both of the latter items facilitate communication within the ETSS. Details of the computer complex selection rationale and requirements are included in Appendix M. To arrive at determination of the optimum complex, it was necessary to review the necessary constituents of a digital computer complex and analyze the possible variations of organization. Three possible configurations were analyzed.

a. Single processor - a single central processor unit and its input/output processor.

b. Multi-processor - two or more central processors, each with its own memory, as well as a common or shared memory.

c. Multi-computer - two (or more) separate, independent central processors, each with its own input/output processor and with its own memory units.

Table 4 (Page 91) is a comparison summary of the three possible configurations.

Computer loading for the complete ETSS is estimated to be approximately 96,000 words of core storage configured as shown in Figure 3 (Page 92). These figures include estimates that will enable the simulation and research function to be performed concurrently. The estimate also includes 20 percent spare capacity. It is extremely significant that the computer loading estimates, as detailed in Appendix M, allow maximum storage and processing for the detailed mathematical models that are required for satisfactory simulation. This will facilitate flexibility in selection of experimental models to enable determination of the optimum.

Finally, although 20 percent spare capacity is a necessity, it was determined that the ETSS computer complex must be capable of: 1) increased expansion beyond the space capacity if required; and 2) the ability to start on a slightly reduced scale and expand as required in the most economical fashion.

TABLE 4. COMPARISON OF COMPUTER CONFIGURATIONS

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Single Processor	. Programming Ease . Flexibility of Program Memory Assignment	. All Functions Dependent on One Processor . Limited Real-time Research Capability . Complex Executive
Multi-Processor	. Permits Real-Time Research and Simulation . Permits Some Capability in Case of One CPU Failure . Executive Requires Less Overhead for Facility	. Redundant Programs . More Difficult to Program
Multi-Computer	. Permits Experimentation and Simulation Independently	. More Hardware Required

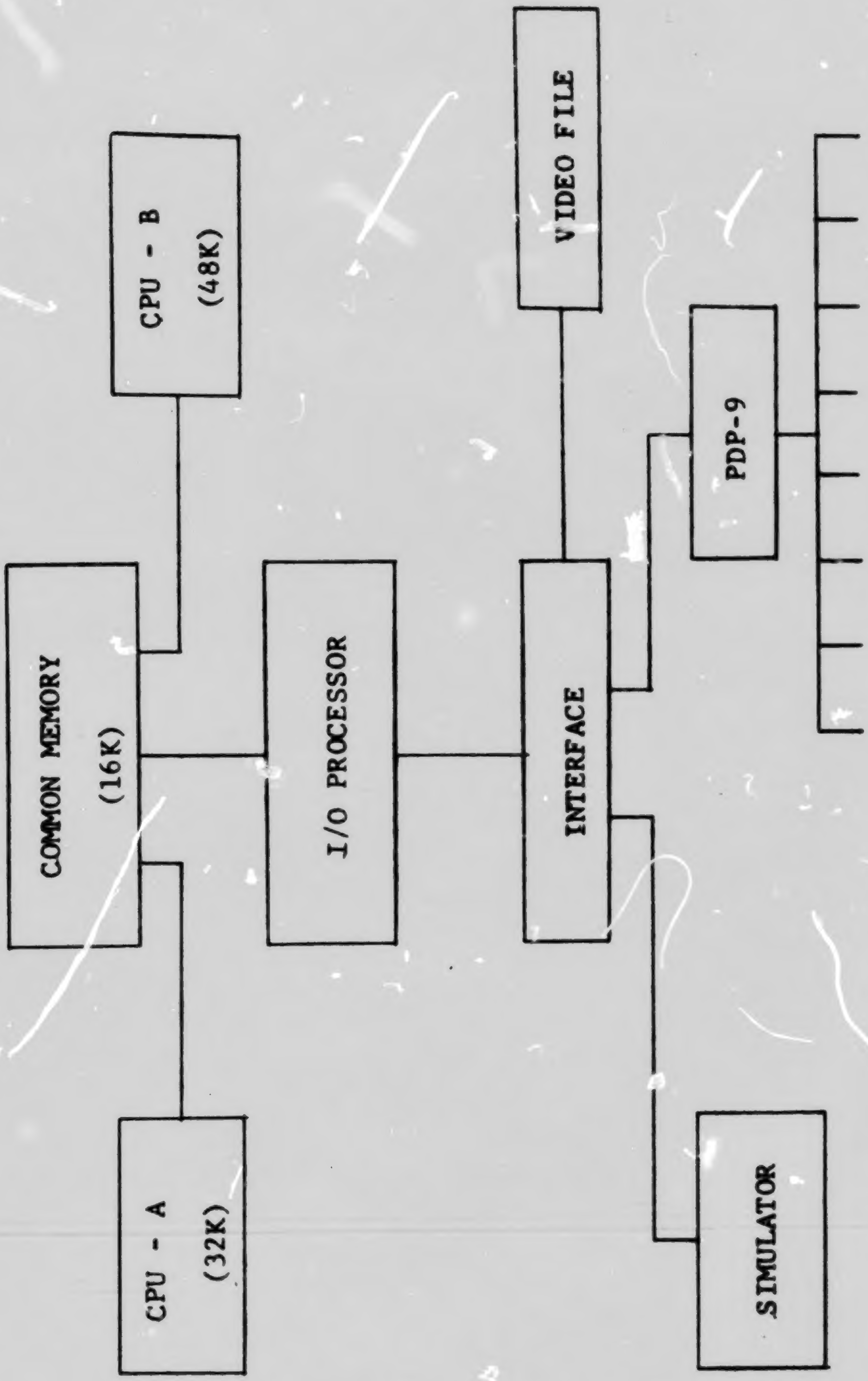
CPU - B
(48K)
VIDEO FILE
COMMON MEMORY
(16K)
I/O PROCESSOR
INTERFACE
PDP-9
TERMINALS
CPU - A
(32K)
SIMULATOR

Figure 3. ETSS Computer Configuration

2.3 MONITORING AND CONTROL. Means must be provided to enable the experimenter to initiate and maintain control during an experiment and data must be provided to enable him to evaluate results. Control during the experiment should include such capabilities as altering dynamics and changing information available to the subject. This, in turn, imposes requirements on the monitoring system to provide proper content and format of information to the experimenter to enable him to make changes.

It was determined that the most effective way of implementing these requirements would be through use of a computer terminal. The terminal would be treated as a time-shared peripheral device interfacing with computer programs. The experimenter would require analyses programs to assist him in determining whether changes are required for success of the experiment. The experimenter would also require access to results of related previous experiments in order to perform comparative studies. The standard CRT computer terminal can perform this function but the price in computer mass storage is extremely high; the Videofile system provides the same form of output but costs less in terms of mass storage. **Table 5 (Page 96) presents a comparison of mass storage costs, and substantiates the previous claim.**

In addition to analytical monitoring, some experiments require real-time monitoring capabilities. This function can be performed by reconfiguring the modular panels as required.

2.4 CUSTOM HARDWARE DESIGN STUDIES. One of the major goals of this study, maximum flexibility with least equipment, led to several custom hardware design studies. The design studies covered subject stations design, experimenter station design, flexible simulation models and audio-visual instructional devices. These studies, which are detailed in Appendix L, resulted in the following:

a. The necessity for flexibility in subject station designs can be provided by a unique junction panel that is used to wire each instrument to the required interface junction. Plug-in connectors are also used to facilitate rapid, simple instrument installation.

b. A multi-purpose trainee compartment provides medium fidelity representations of subject station configurations, and utilizes a projection CRT and closed-circuit video to create the experiment scenario.

c. A flexible multi-purpose experimenter console, which includes a library terminal (Videofile) and a standard computer peripheral CRT.

d. A concept for an audio-visual device combining all features of separate available devices was formulated, and brief system description was generated.

e. The use of generalized math models for all types of simulation was investigated. However, it became evident that this area requires an in-depth examination of about the scope of the ETSS study itself. Hence, only suggested approaches resulted.

2.5 DATA FLOW. A variety of types of data are transferred between the various ETSS subsystems. Figure 4 (Page 95) identifies the flow of data as well as the kinds of data that will be transferred by the ETSS, and the following are the three principal data types.

a. Subject Station Data - These data, available at each of the subject station -- from the audio-visual units to the vehicle simulator -- serves two functions: 1) to initiate any system changes via the computer complex imposed by new values, and 2) in either raw or modified form, to update performance evaluation.

b. System Outputs - These data are the computed response to subject inputs, and are required to update status of the system.

c. Experiment History - This data, which must be available, includes technical reports and descriptions and results of previous experiments.

2.6 HUMAN FACTORS ANALYSIS OF THE EXPERIMENTER'S STATION. The components of the Experimental Training Simulation System were selected primarily for their functional capabilities in support of experiments considered essential to the Human Factors Laboratory. They were also selected to impose a minimum of technical requirements on the personnel expected to employ them. The following functions will be performed at the experimenter's station:

Setup - The experimenter must insert into the simulation system the initial conditions under which the subject is to perform, including the criteria to be used in the evaluation

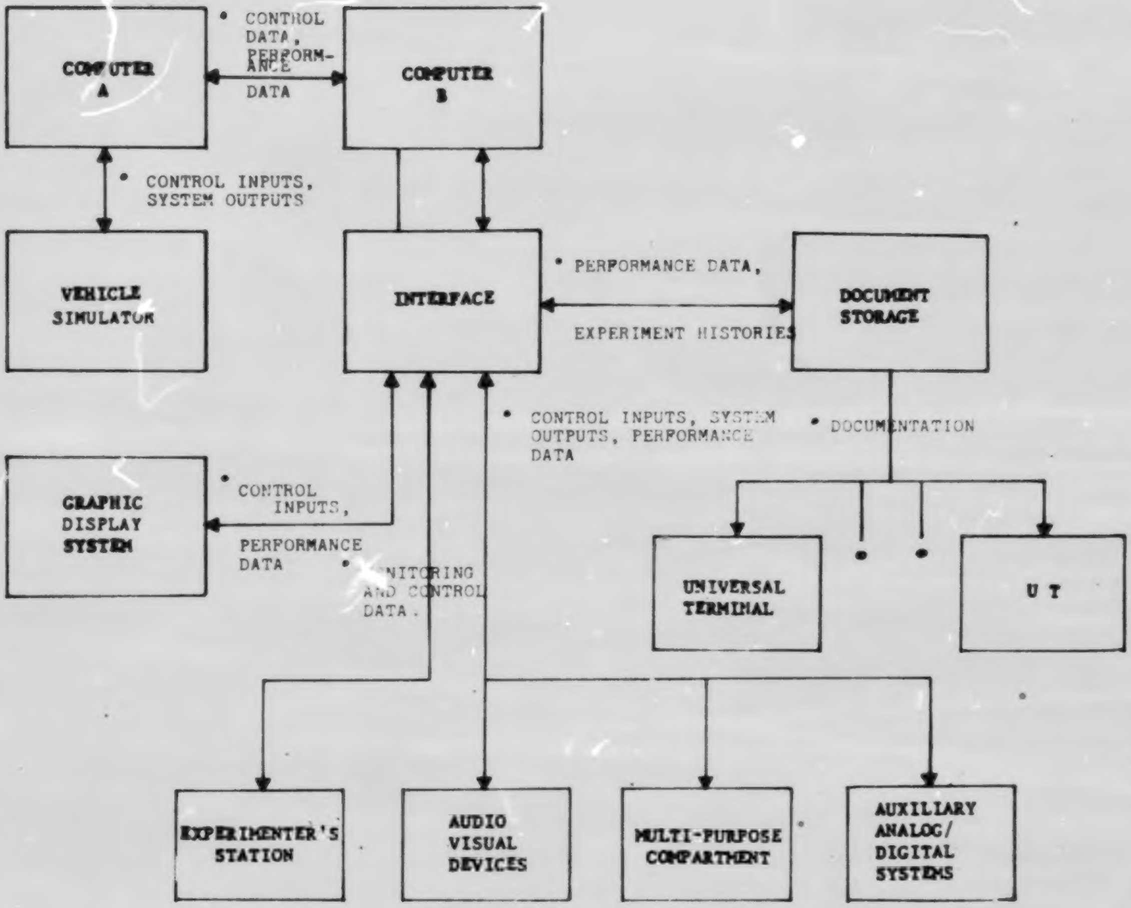
COMPUTER A
• CONTROL DATA, PERFORMANCE DATA
COMPUTER B
• CONTROL INPUTS, SYSTEM OUTPUTS
VEHICLE SIMULATOR
INTERFACE
• PERFORMANCE DATA, EXPERIMENT HISTORIES
DOCUMENT STORAGE
• CONTROL INPUTS, SYSTEM OUTPUTS, PERFORMANCE DATA
• DOCUMENTATION
GRAPHIC DISPLAY SYSTEM
• CONTROL INPUTS, PERFORMANCE DATA
• MONITORING AND CONTROL DATA
UNIVERSAL TERMINAL
U T
EXPERIMENTER'S STATION
AUDIO VISUAL DEVICES
MULTI-PURPOSE COMPARTMENT
AUXILIARY ANALOG/ DIGITAL SYSTEMS

Figure 4. ETSS Data Flow

TABLE 5. COMPARISON OF ON-LINE DOCUMENTATION STORAGE COSTS*

FILE SIZE AND STORAGE MEDIA	25 CHARS. PAGE/RECORD	75 CHARS. PAGE/RECORD	350 CHARS. PAGE/RECORD	2500 CHARS. PAGE/RECORD	5000 CHARS. PAGE/RECORD
500,000					
Page File					
Digital Disc	$12,500	$37,500	$187,500	$1,250,000	$2,500,000
Digital Strip	160,000	160,000	160,000	500,000	1,000,000
Videotape	108,000	108,000	108,000	108,000	154,000
1,000,000					
Page File					
Digital Disc	$25,000	$75,000	$375,000	$2,500,000	$5,000,000
Digital Strip	160,000	160,000	160,000	1,000,000	2,000,000
Videotape	154,000	154,000	154,000	154,000	292,000
10,000,000					
Page File					
Digital Disc	$250,000	$750,000	$3,750,000	$25,000,000	$50,000,000
Digital Strip	160,000	300,000	1,500,000	10,000,000	20,000,000
Videotape	1,352,000	1,352,000	1,352,000	1,352,000	3,042,000
40,000,000					
Page File					
Digital Disc	$1,000,000	$3,000,000	$15,000,000	$100,000,000	$200,000,000
Digital Strip	400,000	1,200,000	6,000,000	40,000,000	80,000,000
Videotape	5,408,000	5,408,000	5,408,000	5,408,000	12,168,000

* Modern Data, January 1970, p.68

of his performance and the formatting of performance monitoring data to be displayed on the CRT. Data employed in the initial setup will be formatted for insertion by means of the keyboard, with some of the more universally employed parameters being controlled by the pushbuttons and thumbwheel switches incorporated in the experimenter's station. Formatting of initial setup data can be accomplished with standardized program forms made up to be used with the panel components and configurations finally selected for the experimenter's station.

Subject Monitoring - Particularly during pilot experiments, the experimenter will monitor subject performance closely to sense and evaluate performance trends having significance for the design of later, major experiments. In some instances, informal data collection and analysis through real-time performance monitoring will suffice to resolve the design questions posed by the experiment. In other cases, monitoring will only serve to verify the validity of the experimental approach and to form an informal concept for later evaluation of formal data. The performance monitoring function will be facilitated by formatting the CRT display for data and data forms consistent with the experimenter's needs and on-line capacity for real-time data interpretation.

Data Retrieval - The controls and displays at the experimenter's station will permit the retrieval of data stored in the system computer. Data from specific experiments and documents will be retrieved for analysis using the station keyboard, CRT, and printer.

Data Analysis - Programs can be developed for the analysis of data from specific experiments and for the comparison of data from experiments stored in the computer. Other data may also be introduced for analysis, using the keyboard and CRT display.

The design of the experimenter's station is predicated on the use of programs for data insertion and analysis prepared by a computer programmer. The station will not require extensive special capabilities for computer programming on the part of the human factors experimenter, assuming the availability of standardized programs.

2.7 ETSS SUPPORT REQUIREMENTS. Although the subjects within this section cannot be categorized as task areas, it has been evident throughout the course of this study that two selected facilities are essential to effective ETSS implementation:

1. Documentation Facility

2. Production Facility

2.7.1 Documentation Facility. This facility is required to support the ETSS by enabling ready availability and access to reports, in-house studies and previous experiment history. This will not only facilitate experimentation and data analysis, but will provide laboratory personnel with current state-of-the-art in training technology. To the present, printed reports and microfilm techniques have been utilized for library references, but with the educational, military and commercial/industrial communities constantly seeking more effective methods of training and learning, the output of relevant research is growing at astronomical rates. It is, therefore, imperative that an automated technique be employed that will meet this requirement.

The ETSS documentation facility must be capable of handling various types of data, and facilitate efficient storage, simple access and inexpensive expansion. It should also have the following desirable capabilities:

1. Inexpensive storage of and immediate access to abstracts. (See Table 6, Page 100)

2. Storage of and hardcopy printout of entire reports.

3. Automatic search capability by identifiers, including author or source, subject, report number and title/subject keyword.

4. Storage of computer programs.

2.7.2 Production Facility. The second support facility is needed to prepare artwork, such as visual aids and panel and instrument paste-ups, and experimental trainee station mockups. Thus, the requirements will include illustrating or drafting tables and appropriate supplies as well as electronic, mechanical and woodworking tools.

SECTION V

DISCUSSION

Because of the unique requirements on the ETSS, it was necessary to evaluate a variety of tradeoffs before a feasible, flexible and efficient system could be specified. The following are examples of the major tradeoff implications inherent in ETSS design:

a. Cost associated with increasing fidelity - The various types of devices to be simulated utilize many different types of instrumentation, even within a single type of operational system. Support of all of the systems requiring experimentation greatly magnifies the problems of simulating instruments for training experimentation. Table 6 (Page 100) identifies the types of instrumentation associated with an aircraft weapon system in terms of associated training tasks, and illustrates the complexity of the problem, and the need for tradeoffs in duplicating training-relevant equipment.

b. Device storage - If the ETSS were to include all of the various types of equipment required, the necessary storage facilities would be prohibitive.

c. Device maintenance - Just as the ETSS would require extensive storage, it would also necessitate a large maintenance team and extensive maintenance equipment. Since each of the devices would be different, the required maintenance skills would be manifold.

d. The need for tradeoffs to arrive at the appropriate, most cost-effective fidelity of system dynamics (simulation software) also was evident. Higher fidelity of simulation requires larger initial engineering effort - analysis, design and programming - and larger amounts of computer storage. The degree of software fidelity must, as for hardware, also consider the variety of system types to be simulated. A brief study was performed aimed at development of a generalized vehicle math model (see Appendix L). Even with the lesser depth of analysis in this area, it was obvious that the level of simulation would have significant implications for math model development. It is strongly recommended that this study be carried further, specifically to the point of producing computer programs to test the validity of the approach.

TABLE 6. INSTRUMENTATION AS A FUNCTION OF THE TRAINING TASK

INSTRUMENTATION	CONTINUOUS CONTROLS								DISCRETE CONTROLS						INFORMATION DEVICES																				
AVIATION TASKS	2 AXIS CONTROL COLUMN	1 AXIS THROTTLE QUAD.	ROTARY RUDDER TRIM	ROTARY AILERON TRIM	1 AXIS RUDDER PEDALS	1 AXIS FLAP QUAD.	1 AXIS SP. BRAKE QUAD.	AUTO PILOT CONTROL	RADIO AND COMMUNICATIONS	POWER (ELEC) GENERATION	FUEL SYSTEM CONTROLS	ENGINE CONTROL SYSTEM	NAVIGATION CONTROLS	PRIMARY FLIGHT INST.ALT.ATT.ASI	NAVIGATION SYSTEM	ENGINE SYSTEMS	FUEL SYSTEMS	EXTERNAL VISION	RADAR HAND CONTROLLER	TEAM REPRESENTATION AIR OR FLEET	STRATEGIC HQ MODEL	CLOCK	MAP BOARD AND PENCILS	STABILIZER TRIM	WEAPON SYSTEM DATA ENTRY PANEL	WEAPON RELEASE	RADAR CONTROLS	WDC CONTROLS	STORES SELECTOR	JETTISON	STORES MANAGEMENT STATUS DISPLAYS	RADAR DISPLAYS	ECM AND ECCM	AIR AND GROUND TARGET SIMULATION	ASW SENSORS
AIRCRAFT CONTROL																																			
COCKPIT OPERATIONAL PROCEDURES	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x												x					
VFR FLIGHT	x	x	x	x	x													x						x											
TAKEOFF	x	x	x	x	x	x			x	x		x		x	x	x	x	x						x											
LANDING	x	x	x	x	x	x	x	x	x				x	x				x						x											
LOW ALTITUDE MANEUVERING	x	x			x	x								x	x			x																	
HIGH ALTITUDE MANEUVERING	x	x			x			x						x	x																				
FORMATION FLIGHT	x	x	x	x	x		x		x					x				x						x								x			
IFR	x	x	x	x				x	x				x	x	x								x				x					x			
ATTITUDE CONTROL	x	x	x																					x											
POWER CONTROL		x								x	x	x				x	x																		
ALTITUDE CONTROL	x	x					x	x						x																					
NAVIGATION																																			
RADIO NAVIGATION									x	x			x		x							x										x			
DEAD RECKONING															x			x				x	x												
CELESTIAL NAVIGATION															x			x				x	x												
INERTIAL NAVIGATION									x						x																				
NAVIGATION SYSTEMS OPERATION									x	x			x					x									x					x			
WEAPON DELIVERY																																			
GUNNERY	x	x			x				x					x				x						x	x	x	x	x	x	x	x	x	x	x	
MISSILE	x	x			x				x					x										x	x	x	x	x	x	x	x	x	x	x	
GRAVITY ORDNANCE	x	x			x								x	x	x			x						x	x	x	x	x	x	x	x	x	x	x	
INDIVIDUAL TACTICAL OPERATIONS																																			
AIR TO GROUND	x	x			x				x				x	x	x			x	x					x	x	x	x	x	x	x	x	x	x	x	
AIR TO AIR	x								x					x				x						x	x	x	x	x	x	x	x	x	x	x	
ANTISUBMARINE	x												x	x				x	x			x		x	x	x	x	x	x	x	x	x	x	x	x
COMBINED TACTICS																																			
ATTACK TEAM OPERATIONS																				x	x	x	x		x	x	x	x	x	x	x	x	x	x	
ASW OPERATIONS																				x	x	x	x		x	x	x	x	x	x	x	x	x		x

e. The need for some type of vehicular subject (trainee) station was established during the Phase I study. For the ETSS to have high fidelity, in terms of subject stations, representation for all types of vehicle systems discussed in Phase I is required. Most of the vehicular experiments concerned with operator station configurations can be performed using the multipurpose trainee compartment or by building trainee stations using modular panels. For experiments aimed at evaluating interactions between several systems in operational situations, a need exists for a specific vehicular type of trainee station. This station must be on a motion base and have a visual system; the configuration would include vehicular control, power control, sensor indicators and controls, auxiliary systems, navigation systems, optical systems, etc. It is anticipated that the skill level in reference to this type of equipment of the subjects will range from the unskilled (local college students), moderately skilled (Boots) to the highly skilled (experienced military personnel). Therefore, the subject station must be sufficiently simple as to accommodate the lowest skill level.

It was for these reasons that detailed attention was directed towards specifying multipurpose equipment wherever possible. The multipurpose trainer compartment, for example, permits a multitude of experiments to be performed even with a low-to-medium appearance fidelity.

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SECTION VI

CONCLUSIONS

The results of this study identified problems in providing an experimental capability for all areas identified as relevant training device development problems for the Naval Training Device Center. Most of these results were related to the anticipated cost of a system capable of fulfilling all ETSS functional requirements stated in Phase I. One of the major objectives throughout Phase II was to meet as many of the functional and training requirements as possible with the least amount of equipment. The following conclusions were reached in attempting to achieve this goal:

a. Subject trainee stations, in the vehicular area, need not be precisely represented for all types of experiments; basic physical relationships should be maintained to permit some degree of correspondence between the experimental situation and the operational device. Low-fidelity experiments can be accomplished in mockup hardware and the multipurpose trainee compartment. For higher fidelity requirements aimed at integrative studies, a simplified vehicular compartment is required. This compartment must, in its maximum configuration, be simple enough so that the least skilled subjects need not participate in a long-term training exercise to be able to perform the experiment. An air cushion vehicle (ACV) simulator appears to fulfill most of the basic requirements for operator station hardware. It is anticipated that the vehicle simulator with motion and visual systems will be procured after other items. The final decision as to the type of vehicle configuration to develop can be made at that time.

b. Since documentation (reports and data) is an essential part of any research and development system, a documentation storage and retrieval capability is extremely relevant for the ETSS. Further, because of the increasing amount of literature being made available, a highly efficient storage system must be used. Filing cabinets and microfilm no longer are adequate for an ETSS-type requirement. Therefore, the Ampex Videofile is suggested for this purpose.

c. The psychologist performing an experiment must have complete control over it. To this end both the hardware and software provided must be completely flexible; multipurpose displays are required to permit flexible modes of information display. Interactive software to the simulation system computer is required to provide complete control over the experiment.

d. The universal terminal will perform and support many functions such as computer assisted instruction, experimenter's console, literature research console, and time sharing terminal for analytical research. To provide simultaneous capabilities, it was determined that eight terminals of this type were required. During an experiment using alphanumeric CRT's for computer managed instruction, the distribution of terminals would be:

3 terminals for the control group
3 terminals for the experimental group
1 terminal for the instructor
1 terminal for the experimenter.

e. The question of fidelity for the ETSS - i.e., motion, visual, dynamics, etc. - poses an interesting problem. It is entirely possible that the majority of device training systems procured by the Naval Training Device Center in the foreseeable future will require only a three-degree-of-freedom motion system to be cost/training-effective, and this fact may be established by the ETSS. It is, however, impossible to perform an experiment to determine how many degrees of freedom are required unless the capability exists to compare up to the maximum possible in experimental situations. Therefore, the maximum capability is required at the ETSS in all areas of environmental simulation fidelity.

SECTION VII

RECOMMENDATIONS

1. EQUIPMENT AND SERVICES

The ETSS provides equipment and programs to permit any combination of eighteen different services or systems: these services may be used individually or collectively to perform the four research and development functions identified. These are:

1) System Research and Development - This includes R&D which concerns complete systems, e.g. ASW trainer, incorporating as much of the real world environment as possible; dynamics, motion, visual, etc.

2) Tactical Decision-making Research and Development - Experiments related to this area will deal mainly with systems associated with tactical environments. The type of equipment includes tactical information displays and controls; an example would be a combat control center.

3) Sensor Research and Development - The main area of experimentation here will be with analog contact displays and associated controls, e.g. sonar displays.

4) Training Aids Research and Development - This area includes experiments dealing with teaching machines; audio-visual, CRT's, etc.

It should be noted that these classifications are purely abstract in nature. They do not imply separate facilities. The ETSS will consist of several types of equipment which used in various combinations will make up each of the above R&D areas. Some equipment will be shared in more than one area.

Table 7 (Page 106) shows the distribution of these services for each of the prime functions of the ETSS. It should be noted that the Ampex Videofile System is the only one of the 18 services that is not directly essential to the experimental functions of the ETSS. Following is a summary of the capabilities of the equipment and services to be provided by the ETSS.

TABLE 7. RELATIONSHIP OF ETSS FUNCTIONS VERSUS AVAILABLE SERVICES

EQUIPMENT AND SERVICES	FUNCTION				
		R & D AREAS			
	DOCUMENTATION SYSTEM	TRAINING AIDS	SENSORY SYSTEMS	TACTICAL DECISIONS	SYSTEMS RESEARCH
1. Ampex Video File Sys.	X	X	X	X	
2. Universal Terminal	X	X	X	X	X
3. Central Computer Complex	X	X	X	X	X
4. 339 Display System		X	X	X	X
5. Multipurpose Compartment			X	X	X
6. Motion System					X
7. Visual System					X
8. Sound System			X	X	X
9. Vehicle Simulation					X
10. Programmable AV Device		X	X	X	
11. Experimenter's Station			X	X	X
12. Panel Mockup Services			X	X	X
13. Photo-Lab Services		X	X	X	X
14. Drafting Services		X	X	X	X
15. Model Shop Services					X
16. TV Studio Services		X	X	X	X
17. Source of Subjects		X	X	X	X
18. Time Sharing System		X	X	X	X

2. SYSTEM RESEARCH AND DEVELOPMENT FUNCTION

The ETSS has the capability to support experiments involving training in complex operator skills that interact significantly with motion, sound and visual cues. The System Research and Development Function consists of a motion platform, a visual system, a system for generating relevant aural cues and a representation of a generalized vehicle operator's station.

2.1 MOTION SYSTEM. The motion system will allow the experimenter to add additional cues to the system being represented, as required. The system chosen for the facility is a synergistic system allowing motion in both translation and rotation for each of the X, Y and Z axes. It is anticipated that it will be primarily used in the system research function, it can also be used in the other three ETSS functions.

Appendices F, G and H discuss the motion characteristics of a number of vehicle types; Table 8 (Page 108) summarizes the maximum motion simulation characteristics required for experimentation in the cues necessary in training vehicle operators.

The characteristics of the ETSS motion system were derived by taking the maximum values from Table 8. Since it is expected that a visual system will be mounted on the motion platform with the vehicle cab, a maximum payload capacity of 20,000 pounds is anticipated.

The relative merits of synergistic and cascaded motion systems are briefly discussed in Appendix I. A cascaded motion system can be procured at lower cost than a comparable synergistic system, and it is easier to program. Further, the cascaded also has the characteristics listed in Table 9 (Page 109). However, it suffers from a number of limitations, including physical size and cross vibrations. Because of these limitations it is recommended that a synergistic system be employed in the ETSS.

The math model used to drive the six degree of freedom motion system derives its inputs from the simulated vehicle equations of motion. The drive signals define the platform orientation, which aligns the natural gravity vector with the computed subject station acceleration vector. The motion cue

TABLE 8. SUMMARY OF MAXIMUM MOTION PARAMETERS*

PARAMETER	AIR	LAND	SEA
EXCURSION LIMITS			
Pitch (degrees)	± 30	± 50	± 30
Roll (degrees)	± 22	± 50	± 27
Yaw (degrees)	± 32	± 20	± 30
Vertical (inches)	± 35	NA	± 48
Lateral (inches)	± 50	NA	NA
Longitudinal (inches)	± 55	NA	NA
MAXIMUM VELOCITIES			
Roll (deg/sec)	± 42	NA	± 7
Pitch (deg/sec)	± 50	NA	± 3
Yaw (deg/sec)	± 15	NA	± 60
Vertical (in/sec)	± 32	NA	NA
Lateral (in/sec)	± 24	NA	NA
Longitudinal (in/sec)	± 24	NA	NA
MAXIMUM ACCELERATIONS			
Roll (deg/sec^2)	143	NA	± 50
Pitch (deg/sec^2)	73	NA	± 50
Yaw (deg/sec^2)	± 100	NA	± 50
Vertical (in/sec^2)	± 300	± 960	± 1556 (½ sec)**
Lateral (in/sec^2)	± 230	± 960	NA
Longitudinal (in/sec^2)	± 230	± 960	NA

* **Appendices F, G and H**

** Typical duration

TABLE 9. TYPICAL CHARACTERISTICS FOR ETSS MOTION SYSTEM

EXCURSION LIMITS		
Pitch	± 50	(degrees)
Roll	± 50	(degrees)
Yaw	± 32	(degrees)
Vertical	± 48	(inches)
Lateral	± 50	(inches)
Longitudinal	± 55	(inches)
MAXIMUM VELOCITIES		
Roll	± 42	(deg/sec)
Pitch	± 50	(deg/sec)
Yaw	± 60	(deg/sec)
Vertical	± 32	(in/sec)
Lateral	± 24	(in/sec)
Longitudinal	± 24	(in/sec)
MAXIMUM ACCELERATIONS		
Roll	± 143	(deg/sec^2)
Pitch	± 73	(deg/sec^2)
Yaw	± 100	(deg/sec^2)
Vertical	± 1556	(in/sec^2)
Lateral	± 960	(in/sec^2)
Longitudinal	± 960	(in/sec^2)

math model also generates drive signals to define the required angular and translational acceleration onset cues, as well as the subsequent subliminal velocity and position washout motions.

To further enhance the kinesthetic cue capability, it is recommended that the synergistic motion system be augmented by inclusion of a g-seat, similar to the devices developed by Link/Miles and Goodyear Aerospace Corporation.

Devices in addition to the vehicle station can be mounted on the motion platform. Hardware for experiments in which motion cues have heretofore been considered unnecessary or distracting can be emplaced on the platform to permit experiments to compare the relative advantages or disadvantages of including motion in specific training exercises.

2.2 VISUAL SYSTEM. It is recommended that the visual system be procured in two successive stages: the first will provide a relatively simple capability at low cost; and the second a comprehensive, sophisticated capability at greater cost. Each stage will permit experimentation in any of the ETSS functions, but it is likely that the full visual system will be used primarily in the major area of systems research, due to its cost, complexity and relevance.

2.2.1 Stage I. Point-Light-Source Projection System. It is recommended that the initial visual system be a point light source projection system utilizing a wrap-around screen. A point light source projection system, together with an orthophotographic transparency, can produce an image intensity of 1 to 2 foot-Lamberts with moderate image resolution for comparatively low cost. This will permit experiments in which two-dimensional cues are relevant, such as in aircraft attitude control. If the scene contains only two-dimensional images, correct perspective may be maintained. A review of visual requirements for the individual vehicles likely to be simulated indicates that the projection screen should have a field of view of 240 horizontal degrees by 165 vertical degrees. The point light source should have the capability for rotation about each of the X, Y and Z axes.

Since the ETSS is required to be as flexible as possible, it is important that the visual system have this same flexibility. Therefore, it is recommended that the visual projection screen and the point light source projection sphere be mounted on a framework that will facilitate its mounting and removal from the motion system as required.

It is recommended that the screen be at least 10 feet away from the eyepoint to allow the subject to change eye focus from the work station to the horizon and back. This implies a structure providing a wrap-around of 240 by 165 degrees on a 15 foot spherical radius.

2.2.2 Stage II. Digital Computer Image Generator. This system will provide the ETSS with an extremely comprehensive visual capability. The system comprises a digital computer image generator that provides a full-color visual display over a viewing angle of 100 x 130 degrees. It is recommended that the system be capable of generating about 1500 edges, and that at least three images within the scene be provided with their own set of transformations allowing individual motion in their own reference frame. The image presented is defined by a math model and the content of the scene is constrained only by the degree of sophistication of the math model. Since a vertical field of view is required with an angular resolution of 4 arc minutes, at least 2500 line pairs are required. This is beyond the capabilities of present day TV projection systems and, therefore it is recommended that the overall visual capability be comprised of a number of smaller TV displays. The 100 by 130 degree field of view requirement may be met by using a viewing system consisting of a number of separate TV projections on a 15 foot radius screen, or by use of a number of "pancake window" displays developed by Farrand Optical Company.

Again, in the interest of experimental flexibility, it is recommended that the visual system be designed for mounting on and removal from the motion platform.

2.3 SOUND SYSTEM. It is recommended that the ETSS include a capability for analyzing and generating aural cues. A standard sound rack (40) is recommended, to be employed in defining aural cue requirements for training device applications.

The recommended sound system will provide a capability for synthesizing all relevant environmental sounds, for use in the Sensory Systems, Tactical Decisions and Systems Research functions. It may also be useful in the Training Aids function where complex sounds may be required for training elementary knowledges and skills.

The sound rack should contain standard sound and logic cards with circuit inputs and outputs brought out to a functionally organized patch panel. This patch panel should be interfaced to the ETSS computer system. The panel should have adequate circuits and controls for synthesizing most sounds that are now anticipated as valuable to training.

The sound rack will also contain special sound analysis equipment, a multi-channel amplifier with a multi-channel speaker system, a small single speaker for directional cues and necessary power supplies for system operation. It is also recommended that the sound rack contain a number of high precision tape recorders for use in the analysis of audio cues.

2.4 VEHICLE SUBJECT STATION. The recommended vehicle simulator is capable of representing a complex vehicle, such as an aircraft, without encumbrance of tactical and communication systems. Allowance is made to facilitate change of configuration, type of vehicle and operating mode. Prime use of this equipment will be in system research utilizing one or more of the visual, motion and sound systems.

The multipurpose compartment will allow generation of a low- to medium-fidelity representation of the vehicle. It may depict electronic displays, external visual scenes, missile firings from launch vehicles and the interior of the simulated vehicle. Other functions may be devised for the device as the need arises. Because of its great versatility, the device will also have a role in the Sensor Systems, Tactical Decisions and System Research functions of the ETSS.

As discussed in Section VI, the Air Cushion Vehicle appears to contain most elements common with the other vehicles to be simulated. It is recommended later in the section that the vehicle station be procured in the fourth module, providing time to further define ETSS vehicle station requirements.

3. TACTICAL DECISIONMAKING RESEARCH AND DEVELOPMENT FUNCTION

The ETSS will support experiments in tactical decision making by permitting the representation of the various systems involved in this type of task. These systems include detection systems, communication systems, navigation systems and armament controls and displays. The various multipurpose ETSS elements used to "build up" each required configuration include:

a. A graphic CRT display to serve as a sensor indicator or navigation display.

b. Modular panels for configuring the control and display portion of the subject station.

c. An alphanumeric display for use as an information and communication device.

d. An experimenter's console to generate and control data presented to the subject. Tactical problems can be preprogrammed and stored on magnetic tape. The experimenter can then concentrate on observation during the exercise.

Preprogrammed problems also permit several subjects to be used during one experiment. Each subject can be provided with a different station, depending on the matters of interest during the experiment, and differences in performance can be analyzed.

4. SENSOR RESEARCH AND DEVELOPMENT FUNCTION

Sensor displays exist in many forms, each with its own unique characteristics: meters, digital readouts and CRT displays with specific phosphors. The following discussion is concerned with the synthesis of displays using cathode ray tubes, including:

Ship navigation radar
Ship weapon control radar
Airborne navigation radar
Airborne weapon system radar
Ground surveillance radar
Precision approach radar (PAR)
Sonar systems
Navigation displays
Electronic countermeasure displays

Since radar, in various forms, is represented in most categories in the above list, it received prime emphasis in the study. It was assumed that if a radar picture can be presented, the remaining types of displays may also be readily represented after suitable mathematical and data manipulations.

The synthesis of any radar system is governed primarily by representation of the following parameters:

Scan rate
Pulse repetition frequency
Radar cross-section
Antenna pattern
Pulse width

A large number of radar simulators synthesize the radar image by using an algorithm based on the characteristic operation of the operational radar set. It is not the intention of the ETSS to provide the ultimate in radar simulation, but rather to provide a capability which may be useful in evaluating training approaches. The complexity of the radar synthesis algorithm is determined by the realism imparted to the above five parameters. For a low-fidelity representation, some parameters may be excluded or held to a constant value.

Since a graphic display is recommended, two approaches to radar synthesis are suggested: the first uses a vector representation of the radar coverage, while the second uses a dot imaging of the radar coverage. The former is the simplest approach in terms of both the display processor requirement and the radar synthesis algorithm. Two approaches to radar synthesis using the Digital Equipment Corporation's Type 339 display system were examined:

a. Standard display system using vector representation of radar return images. (Scan rate PRF, antenna pattern and pulse width are ignored.)

b. Modified display system, using a special CRT with variable-persistence phosphor. (This approach allows formerly ignored radar parameters to be incorporated with some degree of fidelity.)

4.1 STANDARD DISPLAY SYSTEM. The Type 339 display has a P31 phosphor that requires an information update every 1/30 second to prevent flicker. It is intended that the radar return image be synthesized by using a number of vectors of variable lengths. Vectors are chosen in preference to points because of plotting speed; every 1/30 second a new image is painted on the display. The vector coordinate information is updated at an interval dictated by the velocity of the radar-carrying vehicle. For example, if the range of the nearest image is 10,000 feet, the vehicle is traveling at 40 feet/second and the required range displacement error (RDE) is 1%, the vector angle update rate is given by:

$$\text{Update interval} = \frac{\text{Nearest image distance x RDE}}{\text{Vehicle velocity}}$$

$$= 2.5 \text{ seconds}$$

NOTE: This update interval may have to be modified by the psychological criteria associated with "image jump."

In this time interval, each vector has to be adjusted according to which of the two modes the radar is operating:

a. Slaved to some compass heading.

b. Slaved to a specific bearing relative to the carrying vehicle.

For example, the display could be a PPI with either north or the ship's bow at the top of the display. The latter poses the more extensive computation load, because each vector has to be rotated and displaced to allow for vehicle movement and vehicle rotation.

This approach has certain training benefits but it is not representative of the majority of radar displays because of its lack of system parameters, fading returns, sweep image, and other limitations.

4.2 MODIFIED DISPLAY SYSTEM. The modified display system makes use of all the standard 339 hardware but utilizes a special display CRT which allows the signal return to have the correct fade characteristics. The CRT has a special phosphor with a variable persistence. Although the 339 display can display images at eight intensity levels, this is not recommended during the synthesis of radar or sonar imagery. To update the data base in real-time corresponding to target returns and signal fading imposes a very heavy burden on the Central Processing Unit (CPU).

Again, the criterion for the data base update interval is the same as for the standard display approach. From a practical point of view it is feasible to reduce the PRF considerably and yet still obtain a satisfactory picture. The characteristic parameters are inherent by virtue of the point transformations, data manipulation, and control of output data.

The variable-persistence phosphor allows the characteristics of the display CRT to resemble those of operational devices. The purchase of the modified display approach is advocated only if the vector approach is too limiting for training evaluation.

5. TRAINING AIDS RESEARCH AND DEVELOPMENT FUNCTION

The training aids research section of the ETSS can be described functionally through definition of the various devices and techniques recommended to satisfy the goals of the facility.

Computer-aided instruction can generally be defined as the student's interaction with a computer during on-line operation in which the computer performs such functions as problem generation, lesson sequencing, response evaluation and tutorial coaching. In a sense, CAI occurs on any experimental device with automatic features such as demonstration, briefing, adaptive learning, cueing and feedback. CAI utilized in the ETSS facility will include display media consisting of graphic CRT's, alphanumeric CRT's, the special universal terminal and other input devices such as light pens and keyboards.

5.1 AUDIO-VISUAL SYSTEM. This device will be primarily intended for use in the training aids research function. The device may be interfaced to the central computer complex, central documentation system and one or more of the universal terminals. Responses from the subject will cause a spoken commentary and an appropriate picture to be presented. It is equally possible that some of the work in the tactical decisions and sensory systems functions may be performed with this device.

In conjunction with the CAI system, it is recommended that use be made of an A-V system to enhance the capability of the total training aids section. The A-V system will employ slides, motion picture, audio and a student responder system integrated into one unit. These components are illustrated in Figures 5 and 6 (Pages 118 and 119) and discussed in Appendix L, in which the primary description and a discussion of the required facilities for the use of an A-V system are presented.

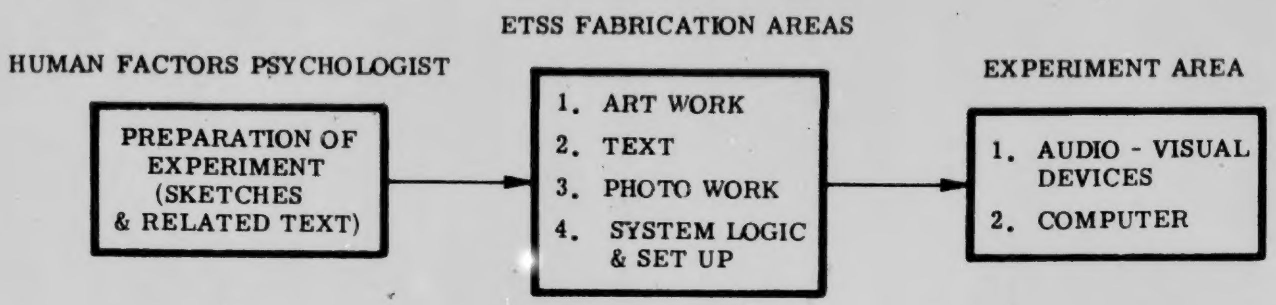
5.2 ALPHANUMERIC AND GRAPHIC CATHODE RAY TUBE. A primary function of the alphanumeric and graphic CRT system will be to experiment with various CAI methods, using a CRT display with keyboard and light pen input in interaction with the computer. The

6. EXPERIMENTER'S STATION

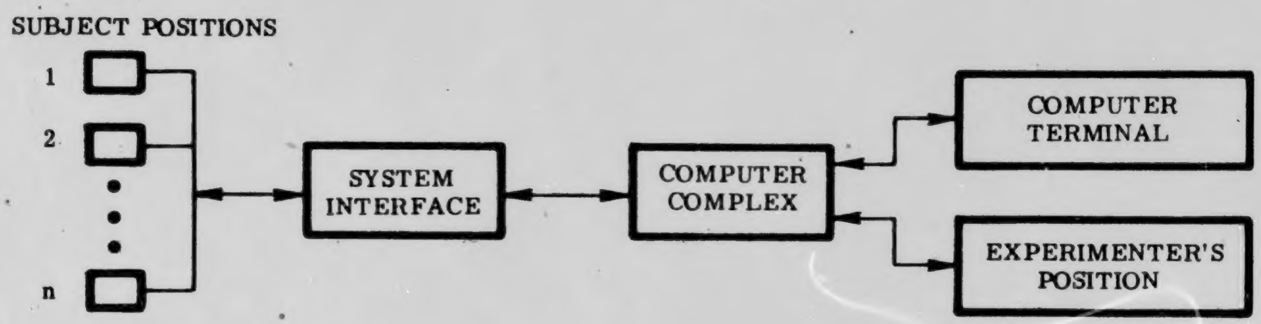
The experimenter's station will facilitate research in optimum methods of controlling an experiment, or permit conducting a simulated mission on the vehicle simulator. By virtue of its modularity, the station may be configured to any desired application and therefore will be applicable to most ETSS functions.

The recommended experimenter's station is flexible and can be expanded to adapt to changing requirements inherent in the utilization of a research device. Special attention has been given to modularity to assure a system of structures and panels that can easily be converted to any desired configuration. Anything less than complete flexibility in format and arrangement could unduly compromise device utilization, resulting in limited utilization modes, awkward visual scan patterns and confusing control-display relationships which could contribute to operator fatigue and error.

Although complete modularity and flexibility are recommended for the experimenter's station, it is anticipated that


HUMAN FACTORS PSYCHOLOGIST
PREPARATION OF EXPERIMENT (SKETCHES & RELATED TEXT)
ETSS FABRICATION AREAS
1. ART WORK
2. TEXT
3. PHOTO WORK
4. SYSTEM LOGIC & SET UP
EXPERIMENT AREA
1. AUDIO - VISUAL DEVICES
2. COMPUTER

(a) PREPARATION OF EXPERIMENTS


SUBJECT POSITIONS
1
2
n
SYSTEM INTERFACE
COMPUTER COMPLEX
COMPUTER TERMINAL
EXPERIMENTER'S POSITION

(b) SYSTEM CONFIGURATION DURING EXPERIMENT

Figure 5. System Requirements and Configuration - (Audio-Visual Slides)-Typical

AREA: Training Aids

SUBJECT: Artillery

TYPE: A-V; Programmed Exp

SUBTITLE: Trajectories

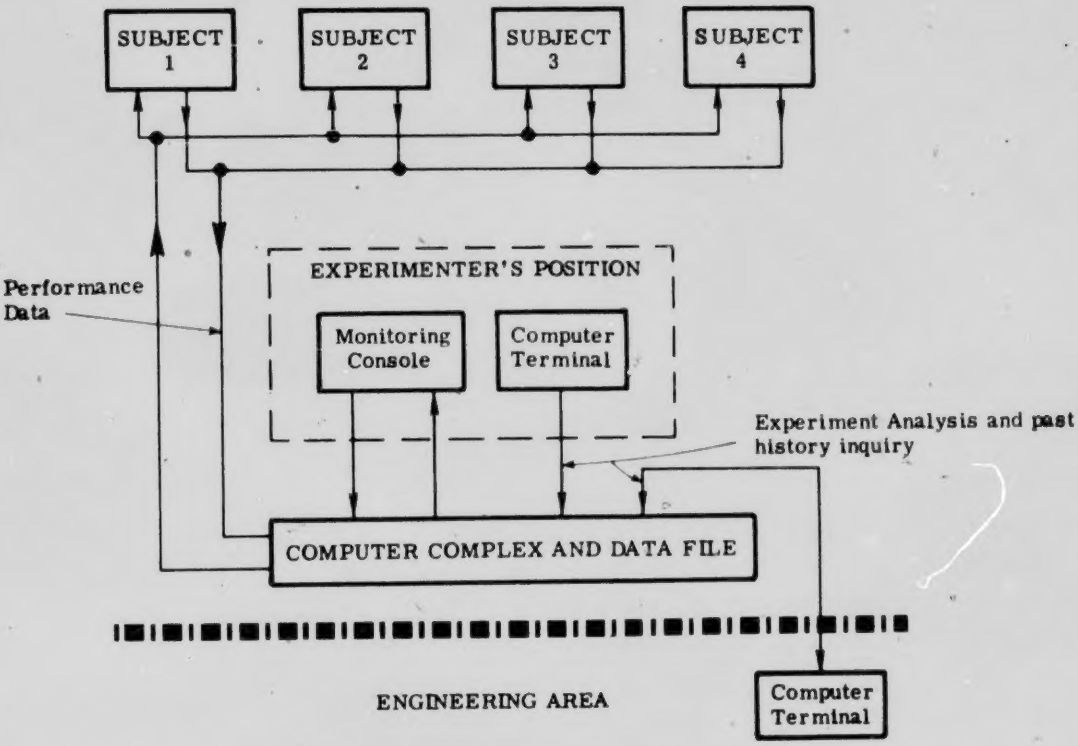

SUBJECT 1
SUBJECT 2
SUBJECT 3
SUBJECT 4
Performance Data
EXPERIMENTER'S POSITION
Monitoring Console
Computer Terminal
Experiment Analysis and past history inquiry
COMPUTER COMPLEX AND DATA FILE
ENGINEERING AREA
Computer Terminal

Figure 6. Typical Experimental Configurement

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a more or less standard configuration will evolve, which incorporates nearly all of the requirements of various experiments. It is expected that the experimenter's station will consist of a CRT, an alphanumeric keyboard, function switches, experimental equipment controls, indicator lights, communications equipment and a printer/plotter.

The CRT/keyboard approach reduces space and hardware requirements, provides needed flexibility and reduces interface, cost, schedule and reliability problems associated with use of a separate indicator or control for each display or control function. This approach minimizes the amount of shifting needed and makes it relatively easy; it maximizes readability of displays and requires just a few standard, easily learned keystrokes to accomplish any control action. The importance of keeping changes primarily in the software area is that the same equipment can be kept in operation full-time with a continuous flow of experiments, with a minimum of teardown or buildup time associated with each experiment. The CRT also has the advantage of variable format so that pertinent information can be selectively displayed. Information can also be displayed in compressed formats, such as summary and computed data.

The keyboard permits the instructor to communicate with the computer. Thus, subject studies can be quickly and easily revised or modified on the spot. The control modules will permit the experimenter to insert discrete parameters (start and stop a time display, start and stop experiment and freeze specific simulation parameters), and control variable simulation quantities (platform motion intensity, sound volume and lighting intensity). Indicator lights can provide equipment status, warning and other relevant discrete event indications.

The basic console module recommended is a commercially available turret section. A variety of slopes and models are available as standard catalog items. With these units, considerable flexibility can be achieved. The turret, in any orientation, can be attached to standard equipment racks or they can be placed on a table top. The result is a modern building-block console system that has a pleasing appearance and is capable of adapting to needs ranging from a very small to a very large console. Special shelf modules are available and wedge cabinets can be obtained if "built-in" horizontal wrap is required. Cabinet structures should be fitted with casters (to facilitate moving) and leveling jacks.

Figure 7 (Page 122) illustrates the flexibility of the turret module. Turrets should be fitted with perforated mounting rails to accommodate a variety of panel modules. Panels should have handles and quick-release, captive fasteners.

The modular panel system should be used throughout the facility for all personnel consoles. Such a system will provide added flexibility in adapting console structures to specific configurations. Standard panels can be prepared with various useful combinations of switch lights, indicator lights, meters, selector switches, potentiometers, thumbwheel switches and so on. A simple means of varying panel and component nomenclature should be provided. Specific systems such as a motion system, sound system or visual system could have permanent control/display panels associated with them and still be of the proper modular sizes.

Even though all panels will not be used in every experimental design, many experiments may require one or more of them. They might also be used advantageously in many subject station arrangements. Because of their usefulness and relatively low cost, they are considered not only worthwhile but essential.

7. CENTRAL COMPUTER COMPLEX

The central computer complex will be the hub of the ETSS and will control, manipulate and receive data from all areas. Control and input of data will be dependent upon the peripheral devices, universal terminals, system mockups and many specialized pieces of electrical hardware. At any time, the experimenter will be able to obtain information about any function being performed in the ETSS, provided it is interfaced with the central computer complex.

7.1 PROCESSOR CONFIGURATION. It is recommended that a multi-processor configuration be used. Since it is required that the main simulation capability be run separate from the other research functions of the ETSS, it is recommended that each CPU have its own input/output processor.

7.2 CORE REQUIREMENTS. To accommodate all aspects of training and training research, it is recommended that the amount of core storage total 96K words in three blocks of 32K, 16K and 48K words.

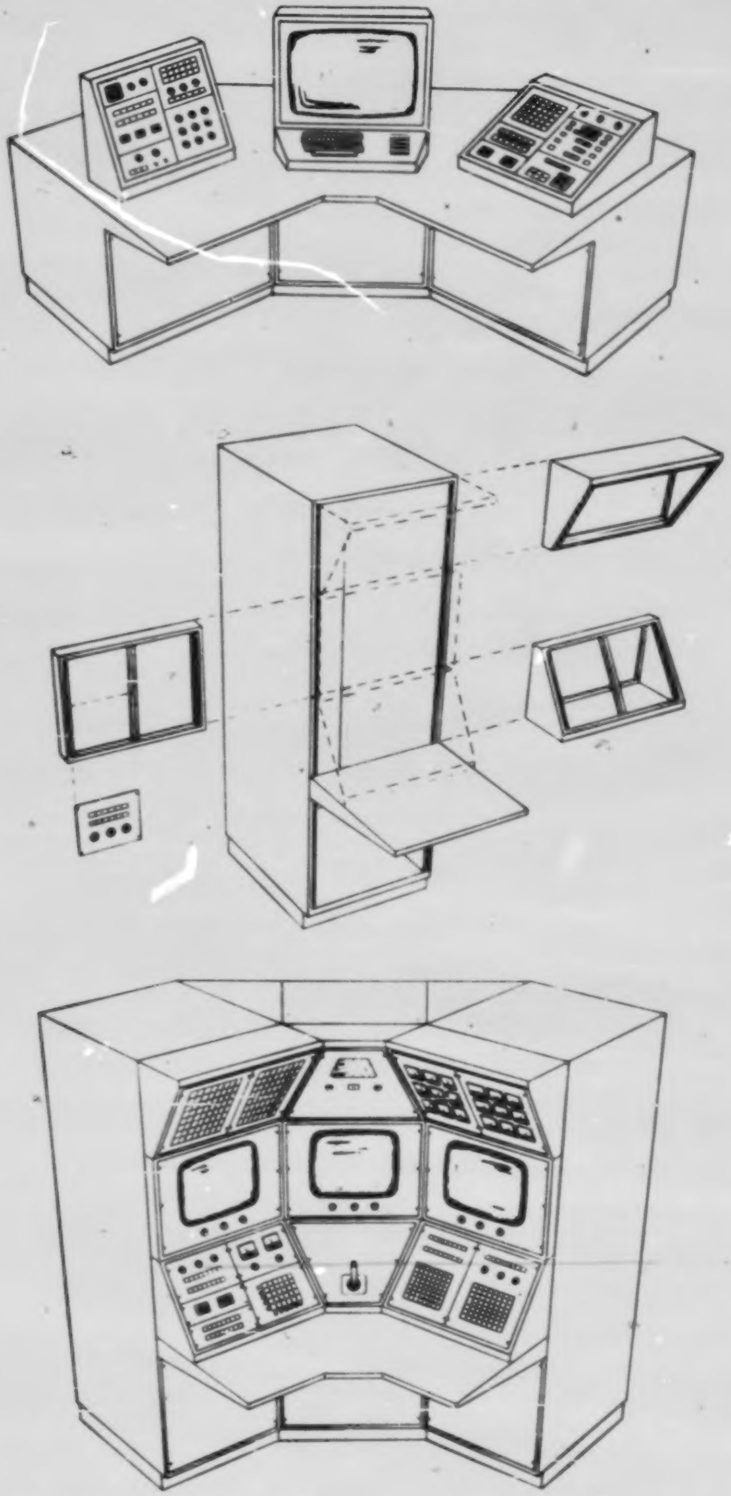

Figure 7. Typical Turret Module

7.3 PROCESSOR SPEED. To cover all aspects of training and training research, it is recommended that the individual processors each have an execution rate in excess of 200,000 instructions per second.

7.4 WORD LENGTH. Depending on the data accuracy requirements and the type of work to be performed within the ETSS, it is recommended that the computer use a word length of at least 32 bits. (See Appendix M)

7.5 INSTRUCTION REPERTOIRE. It is recommended that the instructions allow direct addressing of all cores, or indirect addressing without the time penalty normally incurred when indirect addressing is used in machines with limited direct addressing capability. The instruction repertoire should include floating-point, fixed-point, logical and control instructions.

7.6 SYSTEM INTEGRATION. The recommended configuration of ETSS hardware is shown in Figure 8 (Page 124). It should be noted that each of the central processors, CPU-A and CPU-B, has its own input/output processor: CPU-A will primarily be used for systems experiments, using the visual system, motion system, sound system and the vehicle simulation; and CPU-B will handle the majority of the research functions, time-sharing services and control of the Videofile system. The two processors have 16K words of common memory. The PDP-9 339 display system is interfaced to CPU-B through the general system interface. The general system interface is the hardware interface between IOP-B and the multipurpose compartment, audio-visual devices, experimenter's stations, the auxiliary analog/digital systems and the Ampex Videofile system with its universal terminals.

7.7 TIME-SHARING SYSTEM. A time-sharing system which will be an extension of the central computer complex, will allow the ETSS staff to use the complex as a scientific calculator or to run a program that will generate new data as a result of earlier information. The interface between the operator and central computer complex will be the universal terminal. It is expected that the time-sharing system will prove invaluable to the ETSS staff during execution of an experiment or during the design or research phase of the experiment.

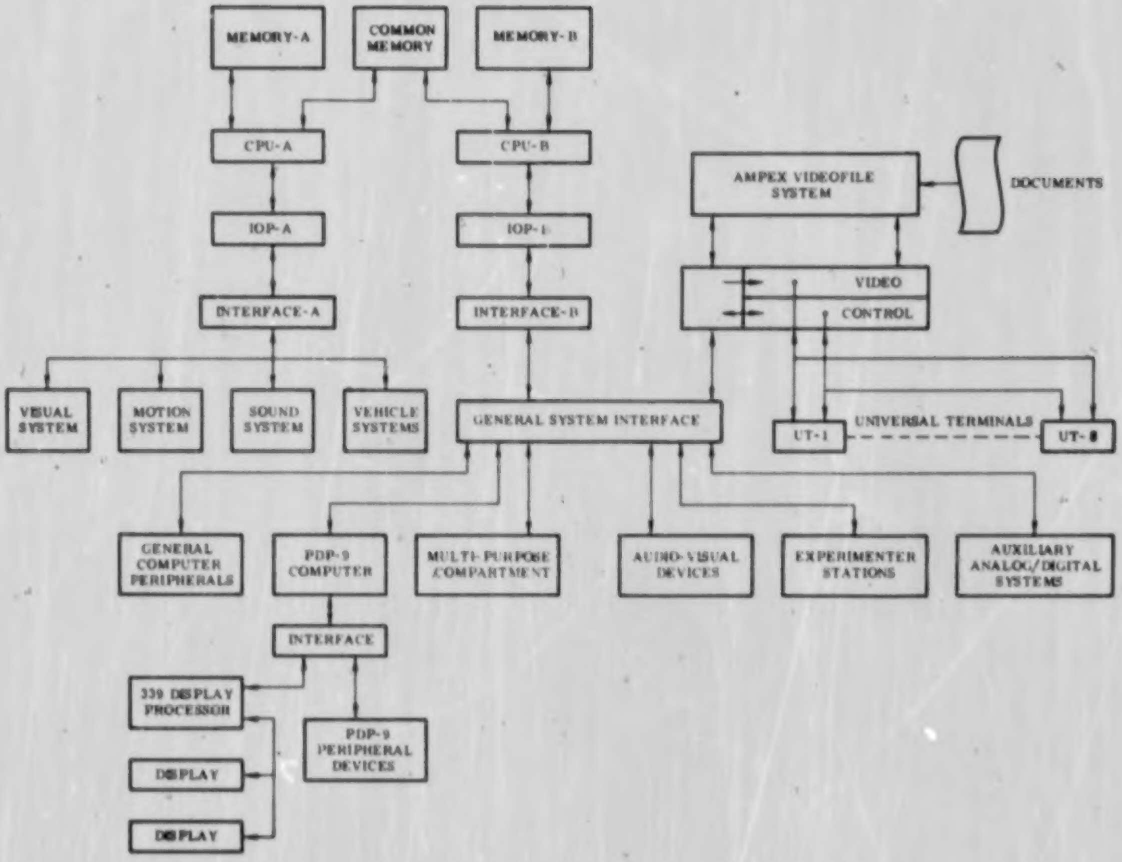
MEMORY-A
COMMON MEMORY
MEMORY-B
CPU-A
CPU-B
IOP-A
IOP-B
INTERFACE-A
INTERFACE-B
AMPEX VIDEOFILE SYSTEM
DOCUMENTS
VIDEO
CONTROL
VISUAL SYSTEM
MOTION SYSTEM
SOUND SYSTEM
VEHICLE SYSTEMS
GENERAL SYSTEM INTERFACE
UT-1
UNIVERSAL TERMINALS
UT-8
GENERAL COMPUTER PERIPHERALS
PDP-9 COMPUTER
MULTI-PURPOSE COMPARTMENT
AUDIO-VISUAL DEVICES
EXPERIMENTER STATIONS
AUXILIARY ANALOG/DIGITAL SYSTEMS
INTERFACE
339 DISPLAY PROCESSOR
PDP-9 PERIPHERAL DEVICES
DISPLAY
DISPLAY

Figure 8. ETSS Configuration

8. SOFTWARE

The software requirements of the ETSS offer a unique challenge to the system designer. Software will also be modular in design and easily modifiable by the experimenter. For this study and discussion, the ETSS software has been divided into simulation/experimentation programs, utility programs and diagnostic programs.

8.1 SIMULATION/EXPERIMENTATION PROGRAMS. The simulation/experimentation programs for the ETSS will consist of all programs required to perform simulation and experimentation. These programs will include the on-line executive program(s), real-time simulation models for the simulator, input/output programs required to operate displays and controls, automatic scoring and evaluation programs, and data comparison and analysis programs required by experimenters and the data retrieval program.

8.2 PROGRAMMING LANGUAGE. The programming language traditionally used for writing flight simulator and/or motion simulator systems has been assembly language. Programs that are coded in assembly language are then translated by assembly programs into machine language or object code. The assembly language program for any particular computer is very similar to the computer language in that instructions and data relate one-to-one. Usually an assembly language instruction must be written for every machine language that results. Coding at this level, therefore, is time-consuming and requires thorough knowledge of the computer instruction repertoire.

Assembly language appears to be used by some simulator manufacturers because the resulting object code may be more efficient when compared to that used by some high-level languages. After a simulator has been delivered, a user agency will normally make comparatively few program changes and, thus, modifications can conveniently be coded using assembly or even machine language. The ETSS, however, will be utilized in quite a different manner. The varying nature of the experimental task will employ a considerable amount of program modification and additions on a regular basis. **For this reason, it is recommended that the operational programs be written in a high-level, efficient compiler language, and the compiler and all documentation be provided with the facility for updating and modification. (Compilers exist** today which generate a very efficient object module.) The provision of a good compiler would relieve the experimenter of much of the tedium associated with coding and debugging in assembly language.

Compiler languages are popular because they relieve the programmer, in an average program, of bookkeeping and transformation requirements that must be tended to when an assembler alone is used. The compiler language may match the language in which the problem is stated and, once the problem is stated, little need be done to convert it to a computer program. Table 10 (Page 127) gives an example of some of the currently available compilers. No attempt has been made to determine which language will best fit ETSS requirements. However, it is possible that a language, which is designed entirely for human behavioral applications (not included in Table 10) might be available and best suited for conversational language communication between experimenter and experimental programs.

It is likely that different levels of programming will be used in the ETSS. The math models associated with the simulation will probably be most efficiently generated by assembly language. However, for experimentation and experimentation programs, a higher-level language is almost a necessity to enable a human factors psychologist to communicate with the computer and subjects/trainees.

8.3 EXECUTIVE PROGRAM. The conventional method of executive control for real-time simulation programs employs a simple scheduling executive. This control program is called at specific time intervals - for example, every 50 milliseconds - by means of real-time clock interrupts. The task of the executive after each interrupt is to schedule and recall the routines to be executed during the next time interval or frame. The scheduling task is generally simple because the iteration rates and, therefore, the execution sequences of the various routines are specified by the programmer and remained fixed during simulation and operation.

The ETSS is certain to require a higher-level executive which, in addition to handling the executive functions of the simulation program, will be able to handle the real-time time-sharing system of the experimenter stations. This concept envisions a structured executive in which the master

TABLE 10. SAMPLE LISTING OF AVAILABLE COMPILERS

	PRIMARY APPLICATION	PROGRAMMING DATA REPRESENTATION	STORAGE ALLOCATION FACILITIES	EXTERNAL SUBROUTINE LINKAGE	USER I/O CAPABILITIES	DEBUG FACILITIES	EASE OF ACQUIRING COMPETENCE IN LANGUAGE	LANGUAGE HIGHLIGHT
SOFT	Specially designed for simulation problems.	Statements very close to math model's format. Fixed decimal @ scale factor data.	Storage fixed at compile time. Fixed common data pool for multi CPU's.	Easy to link separate compilations. Many library functions.	Similar to FORTRAN but less cumbersome formats.	Compile time diagnostics & conditional compilation.	Very easy to learn and gain competence.	Math model coding format. Mixed mode Boolean operations. Automatic scaling of F.Pt. Fract. #'s.
APL	Mathematical computation on time shared terminals.	Upwards from 88 character set. Keyboard printer conversational modes.	Fixed length workspace which can be data managed.	Library functions and declared global functions.	Immediate effect typewriter I/O operations workspace storage.	Syntactical errors detected at compile time. Run time trace mode available.	Relatively easy to acquire a working knowledge.	Concise statement of otherwise cumbersome mathematical operations.
SNOBOL	Rigorous mathematical usage, information retrieval	48 characters set input forms are ordered, sets of chars. forming input strings.	Interpretive execution which provides push-down storage facilities.	Pre-defined SNOBOL coded functions plus machine lang. interpretation function.	System I/O operations for working on strings and string matching.	Very good trace, snap, dump, post-mortem dump, etc.	Precise rules to be obeyed. Powerful and slightly harder to use.	String manipulations and pattern matching.
LISP	List processing and artificial intelligence.	Parenthesized lists, lists of lists, tree structures.	Dynamic re-allocation of storage.	Free references between program structures.	No auxiliary I/O facilities immediate effect I/O operations.	Compile time diagnostics and execution time trace.	Very formal and rigid rules to comply with, slightly difficult.	Recursive routines and dynamic storage allocation.
COBOL	Commercial and business systems.	51 basic characters, many reserved words English language like.	Provision for program segmentation except for data user defines.	System generated built-in libraries.	File maintenance and I/O control operations.	Compile time diagnostics.	Basically very easy to learn and use competently.	Subset of English language, easy to use.
ALGOL	Algebraic and logical applications.	62 chars. in set. Typically flexowriter input. No basic input record length.	Automatic storage allocation for variably dimensioned arrays.	Several standard functions plus user declaration.	Special limited I/O facilities for TTY and paper tape.	Compile time diagnostics. Conditional statement interpreted at run time.	Fairly complex, requires virtually complete knowledge of language.	Machine independent language is formally defined.
FORTRAN	Chiefly scientific and engineering	47 basic chars. fixed length input for mat (full card).	Fixed storage allocation present before run time.	Communicates easily between separately compiled program.	Detailed format specifications implying logical unit lengths.	Compiler diagnostics. User implemented dumps.	Basic statements easy to learn and use.	Similar to mathematical notation.
PL/I	Wide variety of scientific engineering & commercial systems.	60 chars. (48 char. subset) free form statement ended by semicolon.	Controlled storage allocation - combination of FORTRAN and ALGOL.	Communication between separate compilations easy. Many functions, etc.	File, record or stream oriented I/O no physical bounds.	Many compiler diagnostics. Execution time trace, snapshot on conditions very powerful.	Easy or difficult depending on features used.	Powerful, easily handles both business and scientific applications.

control executive would control subordinating executives or sublevel executives in each of the problem areas (i.e., simulation and experimentation).

It has been pointed out that scheduling of program utilization on a fixed framing basis is very wasteful of machine time. Repetition rates of the various routines that are established to provide good response during dynamic conditions can be far greater than is necessary during steady-state conditions. For example, a repetition rate of five solutions per second can provide adequate dynamic response for most aircraft engine equations but, during steady-state (i.e., cruise) conditions, updating the equations every two to three seconds should be sufficient to account for slowly varying ambient conditions.

One obvious method of providing more efficient scheduling would be to design an executive program that would schedule all routines on an interruptible basis with rates dependent upon operating conditions. For example, engine conditions could normally be executed very slowly, but an interrupt caused by a change in power setting would cause the program iteration rate to be greatly increased. Although this type of executive is more sophisticated and requires more processor time, the overall increase in program efficiency could theoretically justify such increases.

Unfortunately, the nature of simulator operation is geared to worst-case dynamic conditions, which tend to occur in most aircraft systems at the same time. For example, during a final or missed approach, flight controls are being exercised, hydraulic systems are changing, radios are being tuned and electrical systems are varying. Under these conditions the use of a powerful executive program would only add to the worst-case computer loading. The overall effect would be to save computer time during cruise conditions where additional time is not required, and to waste computer time during critical maneuvers. For this reason, the use of a powerful executive to respond to program interrupts is not recommended for the simulation of aircraft systems.

On the other hand, for the time-sharing procedure of the experimenter stations an interruptable executive is quite feasible. This would enable the executive to scan or poll individual stations to see if they are on the air or not, and bypass any attempt at I/O operations with the stations not currently being utilized in experiments. The ETSS will contain a large number of instructor and experimenter terminals and, therefore, it appears desirable to interrogate these terminals on an "as required" basis.

On the basis of these considerations, it is recommended that the ETSS executive program be structured to provide for interruptable scanning of selected terminals and/or consoles.

8.4 MODULAR PROGRAMMING. It is recommended that the facility utilize modular programming in program design. This is especially important in view of the unknown nature of experimentation and the need for flexibility in modification of existing programs.

8.5 UTILITY PROGRAMS. Utility programs are routines used for loading, dumping, formating, converting and general digital data handling. Some utility programs for the ETSS will run on-line during simulation exercises; others will be available for off-line utilization. A good set of utility programs is required with any computer installation to facilitate communication with the machine, it being particularly important for the ETSS complex. In addition to the capability of managing all operational simulation processes and experiments, the executive (its structure was discussed in 8.3) must also be capable of servicing requests for utility programs. It is considered essential for the convenience of computer utilization that utility programs be available on call through the TTY or terminal (CRT) to the operator. This means that the executive program must be designed to interrupt coded inputs of the TTY and/or CRT and respond by calling in the appropriate utility program.

The following utility programs are recommended for the ETSS complex:

a. A Compiler - capable of running within the delivered complex and of producing object code in relocatable format.

b. An Assembler Program - that will accept inputs coded in a mnemonic or symbolic language of a particular computer and output object code in relocatable format. The assembler must be capable of assembling individual program modules.

when changes are made, only the affected module need be reassembled. The assembler should also be capable of generating a magnetic tape in standard format, suitable for outputting through a line printer in a hard-copy program listing. This listing should present in parallel columns the following items: relative location of machine language instruction, symbolic language instruction, programmer notation and assembly-program-generated comments. The availability of an assembler will enable the computer user to make changes in symbolic language for routines where the use of the compiler may not be convenient or desirable.

c. A Relocatable Program Loader - that will accept the relocatable object tapes generated by the compiler or assembler and produce an absolute object program in core memory for execution by the computer. The relocatable loader may also be capable of reloading the computer with a previously loaded program that has been dumped on magnetic tape. This loader will, of course, be much faster than the relocatable loader and will enable the entire computer to be loaded in a few seconds.

d. An On-Line Debugging Program - which can be made accessible during the simulation processing to dynamically change core, to provide snapshot dumps of core, to input data to some intermediate storage device in a fully acceptable data format and for other purposes. This program could be used to run in simulated real time, allowing on-the-spot examination of time-dependent parameters. This is especially true for the experimenter process.

e. An On-Line or Off-Line Trace Routine - whose output can be retrieved on a number of peripheral devices, thus permitting immediate or deferred hard-copy examination of results.

f. A Postmortem Dump and Analysis Routine - that returns a hard-copy output. A properly formatted dump of core, compressed if necessary, to preclude printing of consecutive locations containing identical information (e.g., several thousand core locations set to zero). This routine will also provide information such as computer status words, time elapsed from some reference time to the beginning of the execution of the dump routine and various supplemental features.

g. I/O Handling Routines - general in their makeup to eliminate redundant programming by any other programs.

h. A General I/O and Edit Program - that can be used to copy tapes, list files from various peripheral devices, update source coding contained on some storage medium, allow for conversion formatting and various auxiliary tasks.

i. A Disc Management Routine - which will handle all disc functions, including entries, updates, purges, transfers, searches and allocations.

j. Other Programs - more or less dependent upon the computer complex selected, which might include a digital plot routine, instrumentation-oriented programs such as graphic display, audio-visual response programs and hardware interface programs.

8.6 DIAGNOSTIC PROGRAMS. Diagnostic programs are routines that assist the computer operator in checking the status of the computer and computer interface hardware and isolating failure conditions.

The following diagnostic programs are recommended for the ETSS computer complex:

a. An On-Line Loop-Check - of the interface or linkage system to determine that the computer I/O channels and the real-time interface converters are functioning properly. Implementation of this diagnostic will necessitate interface hardware design that closes the loop by tying interface outputs to inputs. Many possibilities exist for providing such interconnection, including mechanical patch boards, complex switching matrices and complete duplication of all channels for test purposes.

b. A Morning Readiness Check - which provides the operator with a Go/No-Go simulator status check. This program would enable the operator to check simulator hardware independent of the operational program.

c. Program Test and Verification - which would enable the operator to verify the performance of the operational program. This feature can be implemented by recording on magnetic tape the program outputs and inputs that occur during an exercise. The master tape would then be used during a diagnostic test to drive the operational program with recorded inputs. The newly computed outputs will then be compared with the previous values stored on magnetic tape and errors and discrepancies will be printed out on the line printer for analysis by the operator. It is envisioned that this program will be utilized to check the correct function of the operational program after each complete mode.

d. An Off-Line Interface or Linkage Test Program - designed to selectively test all interface channels.

e. CPU and Memory Area Level Diagnostics - that will facilitate location and correction of malfunctions. These diagnostics are normally supplied by the digital computer manufacturer as part of the standard software package.

f. Peripheral Equipment Diagnostics - that will test operation of each computer peripheral and will notify the operator by typewriter output if errors are detected.

8.7 PROGRAM MODIFICATION AIDS. The compiler and assembler programs previously discussed will provide means for modifying operational programs for the ETSS facility. However, there are two types of program data peculiar to flight simulators that will require special programs to facilitate modification - function data and radio aids data.

Function data consists of the stored break-point values for all functions of independent variables, and is continually accessed by the linear interpolation routine during program execution. Radio aids data consists of stored parameters for all radio facilities and is accessed with a facility selector routine during program execution. It is of course essential that the simulator user be provided with a convenient means for updating these data blocks. The recommended means is by employing special data packing and formatting programs commonly called function data and radio aids data compilers. In addition, it is envisioned that the ETSS will require other special-purpose program modification aids in the areas of performance evaluation, documentation retrieval and automated training.

9. DOCUMENTATION FACILITY

This system will provide central documentation support service to the ETSS. The system will accept standard document pages or, with slight modification, pages from the standard microfiche negative. By suitable operation with one or more universal terminals, the Ampex Videofile system operation may be extended to include computer-assisted instruction, photo interpretation in the tactical decision function and display system synthesis in the sensory system function.

A documentation facility, in order to be economic, should be easy to use, cost less than earlier document control methods, present information in an easily understood format and should be capable of allowing extensive expansion without detriment to existing information. Previous manual or semi-automatic methods of handling large pools of documents have generally been costly and inefficient. The recently developed Videofile information system appears to offer a satisfactory solution to ETSS requirements.

The Videofile system converts document originals into television electronic images which, with suitable identifying addresses, are automatically filed on magnetic tape. Any individual document page can be easily retrieved, examined, purged or filed in a new location. A television monitor is used to display the document page image and the image may be reproduced as a printed page on request. Since the images are in electronic form, filing, retrieval and sorting may be performed remote from the central file.

The Videofile system consists of a series of flexible and expandable modules to facilitate growth:

a. Filing section
b. Storage - temporary and permanent
c. Viewing
d. Printing
e. System control.

These system modules will be suitably interfaced to the ETSS central computer, to the ETSS universal terminal and to each other to meet the main requirements for the ETSS documentation system. Figure 9 (Page 134) shows the general arrangement of the documentation facility.

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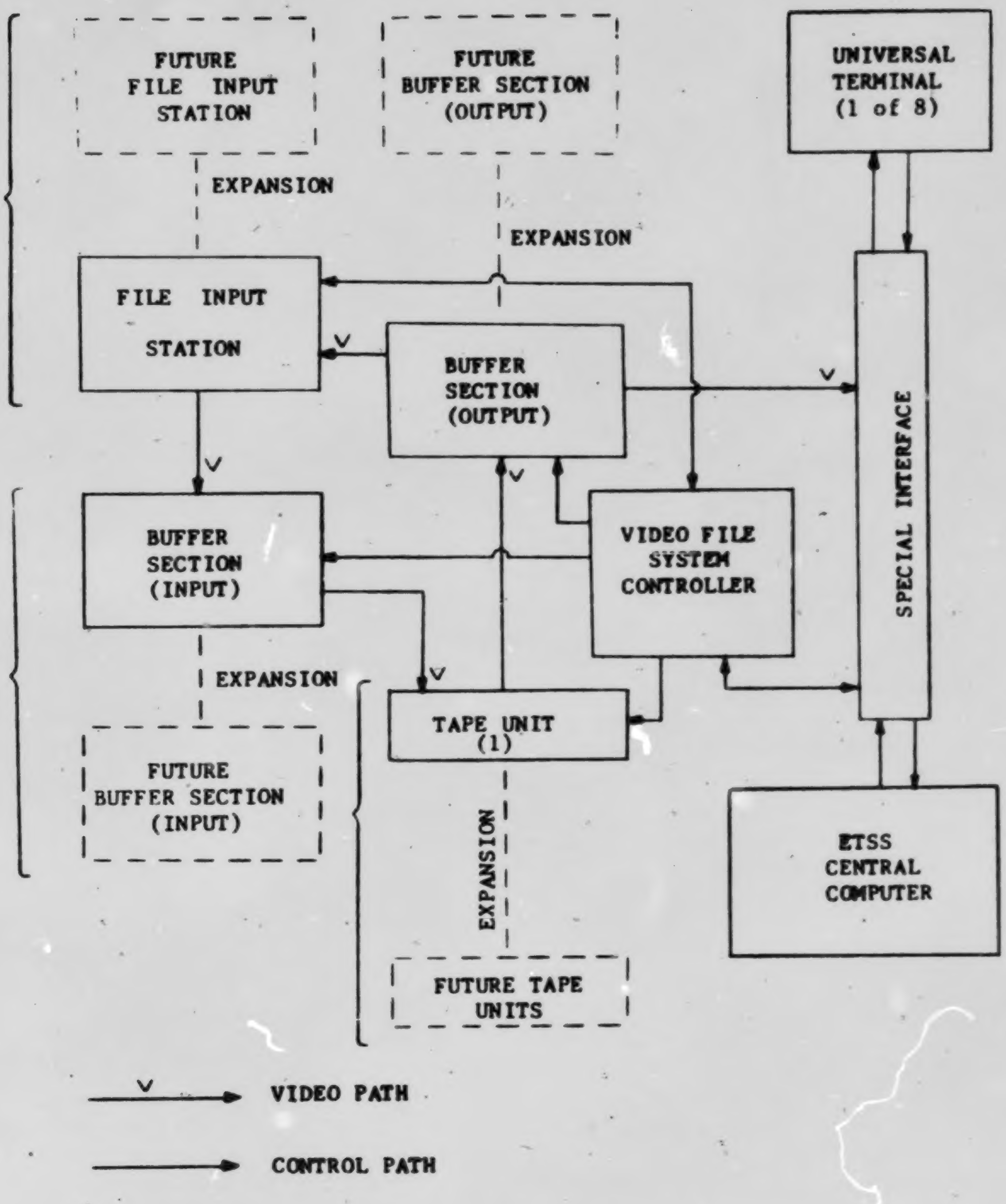

FUTURE FILE INPUT STATION
FUTURE BUFFER SECTION (OUTPUT)
UNIVERSAL TERMINAL (1 of 8)
EXPANSION
EXPANSION
FILE INPUT STATION
BUFFER SECTION (OUTPUT)
SPECIAL INTERFACE
BUFFER SECTION (INPUT)
VIDEO FILE SYSTEM CONTROLLER
EXPANSION
TAPE UNIT (1)
FUTURE BUFFER SECTION (INPUT)
EXPANSION
ETSS CENTRAL COMPUTER
FUTURE TAPE UNITS
V
VIDEO PATH
CONTROL PATH

Figure 9. Schematic of Documentation Facility

9.1 FILE INPUT STATION. The file input station allows any document or microfiche page image to be input to the documentation facility for permanent storage. File input data is scanned by a high resolution TV camera which converts the file data to a video signal, which is stored on magnetic tape by proprietary techniques for subsequent retrieval and viewing. File data input may be specified by absolute address or associative keywords through an input keyboard. An alphanumeric tote is available for verification of input address data. The station should also have the ability to display either the document being copied or selected filed images. Filing speeds should be of the order of one page every ten seconds.

9.2 BUFFER SECTION (INPUT). The input buffer section is a temporary storage device to collect document images at the operator's pace, and place them on the master tape storage units independent of operator action. This reduces the number of search accesses needed to record a complete document. It is anticipated that the average document filed will be less than 50 pages. The buffer section can be expanded to meet the demand.

9.3 TAPE UNIT. The tape unit is the master storage for document pages; each unit will allow about 167,000 pages to be stored on a reel of 2 inch wide magnetic tape. For ease in editing tapes, two tape transports are required: (1) both can carry the same information and multiplex its use according to retrieval requests; or (2) each can carry different information, thus doubling the master file capacity.

Expansion of the master file can be performed either by increasing the number of tape transports and obtaining rapid access times for a particular document page, or by forming a library of tape reels and suffering the penalty of slow access time due to human intervention.

9.4 BUFFER SECTION (OUTPUT). The output buffer section is used as a storage device to hold a number of selected images for output either to the universal terminals or to the file input station. The number of video images in the output buffer section is dependent upon the manner of use of the universal terminals by ETSS personnel. A minimum of eight tracks is required (one for each universal terminal); for the CAI role where the subject is stepping (or browsing) through a text, more image tracks are required. A minimum of 50 image tracks is specified for this unit. Output is to the special interface, which includes a video switching matrix.

9.5 VIDEOFILE SYSTEM CONTROLLER. The Videofile Control Unit directs the interaction of former system modules in a predetermined manner. The controller receives address and function data from both the file input station and the ETSS central computer.

9.6 PRICE SCHEDULE FOR BASE SYSTEM. Prices currently quoted for the basic Videofile system recommended for the ETSS are:

1 - Filing Station	$40,000
1 - Input Buffer Section	38,000
2 - Master Tape File (@ $40,000)	80,000
1 - Videofile System Controller	112,000
1 - Interface Computer to System Controller	30,000
1 - Interface to Universal Terminals	20,000
Total Configuration Cost	$320,000

This base system has a filing capacity of about 334,000 document pages. To achieve an operative system it is necessary to include the price of universal terminals. These terminals allow the user to display or copy any page of any document filed in the documentation retrieval system.

A separate stand-alone filing system with equivalent capacity without interface with the ETSS computer complex would be priced as follows:

1 - Filing Section	$40,000
1 - Input Buffer	38,000
2 - Master Tape File (@ $40,000)	80,000
1 - System Controller	112,000
1 - Printer	56,000
Total Price for Stand-Alone System	$326,000

10. UNIVERSAL TERMINAL

The universal terminal allows communication between the central computer complex and an operator. Communication with the central computer complex may result in rerouting of information to either the Ampex Videofile system, another universal terminal or a display of experimental data. On demand, an operator may obtain a hard-copy print of data displayed on either of the two display systems. The universal terminal will find applications in all functions of the ETSS. A description of the terminal may be found in Appendix M. To complete information about the terminal, the history and pricing of the major components is presented below.

Prices are given for a system comprising eight universal terminals, since the terminals share a common alphanumeric display generation system:

a. ALPHANUMERIC DISPLAY GENERATION SYSTEM.

1 - Data Disc 6600 Display Controller	$30,000
1 - Computer Interface and Matrix	4,500
1 - Keyboard Multiplexer	6,375
8 - Color Channels @ $4500	36,000
8 - Color Monitors @ $2500	20,000
8 - Control Keyboards @ $575	4,600
Total Subsystem Cost for Eight Terminals	$101,475
Total Subsystem Cost per Terminal	$ 12,684

b. HARD COPY SUBSYSTEM.

1 - Electrostatic Printer with a resolution of 80 raster elements per inch	$15,000
1 - Dynamic Memory for Printer	$5,000
Subsystem Cost per Terminal	$20,000
Subsystem Cost per Eight Terminals	$160,000

c. HIGH DEFINITION DISPLAY.

8 - Black & white TV monitors for use with the document retrieval system, @ $5,000	$40,000

d. INTER-SYSTEM INTERFACING.	
Non-recurring Cost	$10,000
Recurring Cost, 8 units @ $2,000	$16,000
e. CABINET.	
8 - Enclosures to contain all above items, @ $2,000	$16,000
f. TOTAL SYSTEM COST	$343,475
g. TOTAL SYSTEM COST PER TERMINAL	$42,934

11. MODEL SHOP FUNCTION

The ETSS Model Shop should act as a support facility. It will facilitate design and fabrication of special fixtures, jigs and experimental apparatus, and modification of existing equipment. The equipment complement should be comprehensive enough to allow fabrication from metals, plastics and wood materials, but should exclude such services as forging, casting and machining of large components. It is not anticipated that a production capability will be required and production equipment need not be specified (for example, capstan or turret lathes, gang drill presses, etc.).

The Model Shop should be arranged into three individually partitioned areas, which would provide:

a. Material and tool storage
b. Machine floor space
c. Welding and hand fabrication workspace.

11.1 MATERIAL AND TOOL STORAGE. The material and tool storage area should contain moderate supplies of wood, fibre board, sheet plastic, sheet metal, rod, tubing and strip in both metal and plastic. Sufficient tools should be stored to keep all machines in operating state, and to allow for a moderate amount of tool breakage and normal wear. Included in the tool inventory should be equipment for accurate measurement and marking out.

11.2 MACHINE FLOOR SPACE. Machine floor space should be reserved for special machinery used in fabrication of special components. Special consideration should be given to acoustic damping and machine accessibility. It is recommended that the following equipment be available to the ETSS staff.

a. Radial drill press
b. Drop bed screw cutting lathe with tailstock
c. Vertical milling machine
d. Surface grinder
e. Rotary grinder (not centerless)
f. High-precision jig borer
g. Power hacksaw
h. Assorted hand power tools

All of the above should be supported by accessories such as vises, indexing tables, etc. to allow maximum flexibility.

11.3 WELDING AND HAND FABRICATION WORKSPACE. The welding and hand fabrication workspace will allow small components to be fabricated by hand in either metal, plastic, or wood materials. The area should be equipped with benches and suitable hand tools; it is recommended that the following equipment be included:

a. Portable oxy-acetylene welding system
b. Power guillotine
c. Folding and bending machine
d. Hammers, files, chisels, hand drills, etc.

12. IMPLEMENTATION PLAN

Since the purpose of this study is to recommend system elements for an advanced experimental facility for the period 1971 through 1975, an implementation plan is presented that will permit a logical buildup of equipment and personnel to meet the needs of future experimental work. The implementation schedule permits a sequential buildup as required by future trends and represents an average or expected trend which in no way limits expansion as required.

The actual plan presented was developed under the assumption that the time frame involved is the 5-year period given above, and that the amount of money expended each fiscal year will be approximately the same. Though the ETSS is discussed in terms of a separate building, this is not to be construed as a prerequisite since the ETSS may be housed in existing Naval Training Device Center areas, if necessary. The plan is illustrated in Table 11 (Page 141) and Figures 10, 11, 12, 13 and 14 (Pages 142-151).

13. MANNING

It is expected that the Experimental Training Simulation System will be procured in increments rather than as a unit. As a result, manning estimates for the total system are discussed only with respect to the types of skills and responsibility required by the system and by its associated components and functions, rather than as absolute numbers of personnel. Further, it is assumed that personnel within the Human Factors Laboratory are capable of performing many of the functions required by the system on a part-time basis.

As more and more of the system is procured and as it becomes more involved in experimentation, the following additional, specially-qualified personnel categories will be required:

a. ETSS Chief of Operations - Plans, directs, coordinates and evaluates the activities of the facility; defines priorities and boundaries of projects; formulates, develops and interprets the policies, purposes and goals of the facility. He is the administrative and technical head of the facility and is responsible for completing the facility's mission, and is responsible for making final decisions regarding operations.

b. Secretary (Chief of Operations) - Telephone and reception duties; keeps supervisor's calendar; receives mail and prepares replies; maintains records and files and performs stenographic and typing services; performs miscellaneous duties related to management of the office.

c. Liaison Engineer - Acts as liaison between the Chief of Operations and subordinates and arranges for conference proceedings.

d. Chief of Project Engineering - Responsible for planning, directing, coordinating and evaluating experiments

TABLE 1 IMPLEMENTATION PLAN

MODULE	EQUIPMENT HDWE/SFTWE	APPROX. COST	EXAMPLES OF EXPERIMENTAL CAPABILITIES OF EACH RESEARCH AREA			
			TRAINING AIDS RESEARCH	SENSOR RESEARCH	TACTICAL DECISION-MAKING RESEARCH	SYSTEMS RESEARCH
1	A. Basic #B Computer with conventional sftw B. Eight audio-visual devices * C. Production facilities for A-V, media * D. PDP-9/339 Display System E. General Systems Interface (I) * F. PDP-9/SIGMA 7 Interface	445,750 24,000 25,000 12,000	Teaching system operations using slides, motion pictures, CRT displays Demonstrating dynamic relationships, e.g. ballistics, using graphic CRT	Use PDP-9/TYPE 339 Display for low resolution target perception experiments	None	None
2	A. Basic Videofile B. Universal Terminals C. Complete computer B Buy D. Utility Software E. Material & Instruments for mock-ups * F. Electro-Mechanical Lab G. General Systems Interface (II)	226,000 197,000 146,000 200,000 50,000	More comprehensive Computer-Managed Instruction using universal CRT terminals. Complex verbal adaptive trng., using audio-visual equipment.	Multi-mode target perception involving operation of system controls.	Simple battlefield experiments, involving Combat Information Center Displays, tactical situation displays, communications nets.	Experiments in the trng of system procedures, such as engine start procedures, navigation system operating procedures.
3	A. Additional Videofile Storage B. Four universal terminals C. Basic #A Computer D. Multi-purpose compartment ** E. Motion F. Cockpit	78,000 146,300 301,250 127,000 300,000 200,000	Multi-position Computer-Managed Instruction permitting control & experimental group to be exercised at the same time.	More complete representation of sensor station permitting more complex learning experiments in scope adjustment and interpretation.	Experiments in tactical team training involving ship - or airborne ASW EW and ECM systems.	Experiments in general vehicular control. Simple display/control relationships.
4	A. Additional Videofile Storage B. Modular experimenters Console C. Complete Computer A D. Long Persistence Scope E. Sound Electronics * F. Visual I G. Interface to Motion, Sound and Visual	150,000 78,000 6,600 69,000 130,000	None	Higher fidelity experiments dealing with radar, sonar-type sensors. A typical experiment would be determining the amount of background clutter to provide for a shipboard radar trainer.	Effect of motion on performance of tactics operators.	High fidelity vehicular training experiments. Landing craft operator trainer. Operational flight trainer experiments.
5	A. Visual II	2.5×10^6	Expanded Computer-Managed Instruction using additional terminals	None	None	High fidelity visual experiments with vehicular station.

* Could be existing NTDC Facility

** Partial capability exists at NTDC

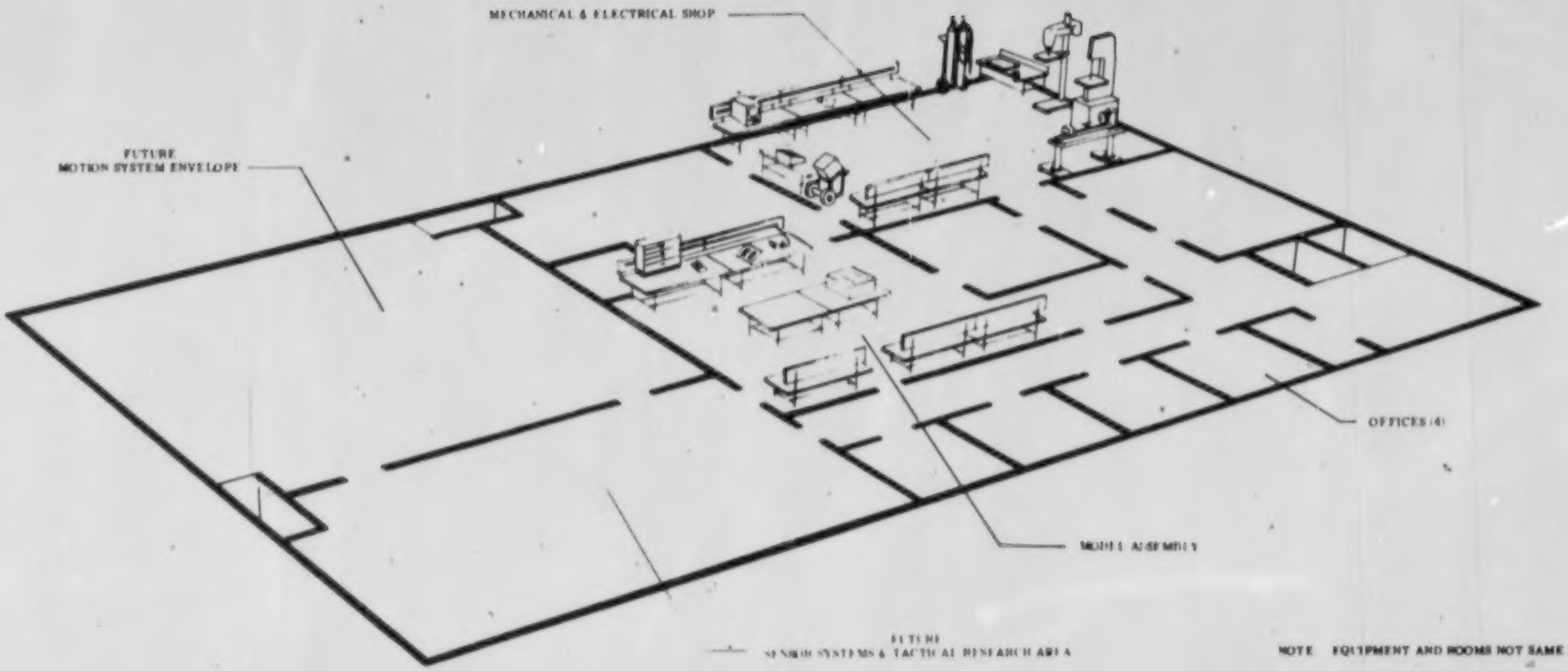
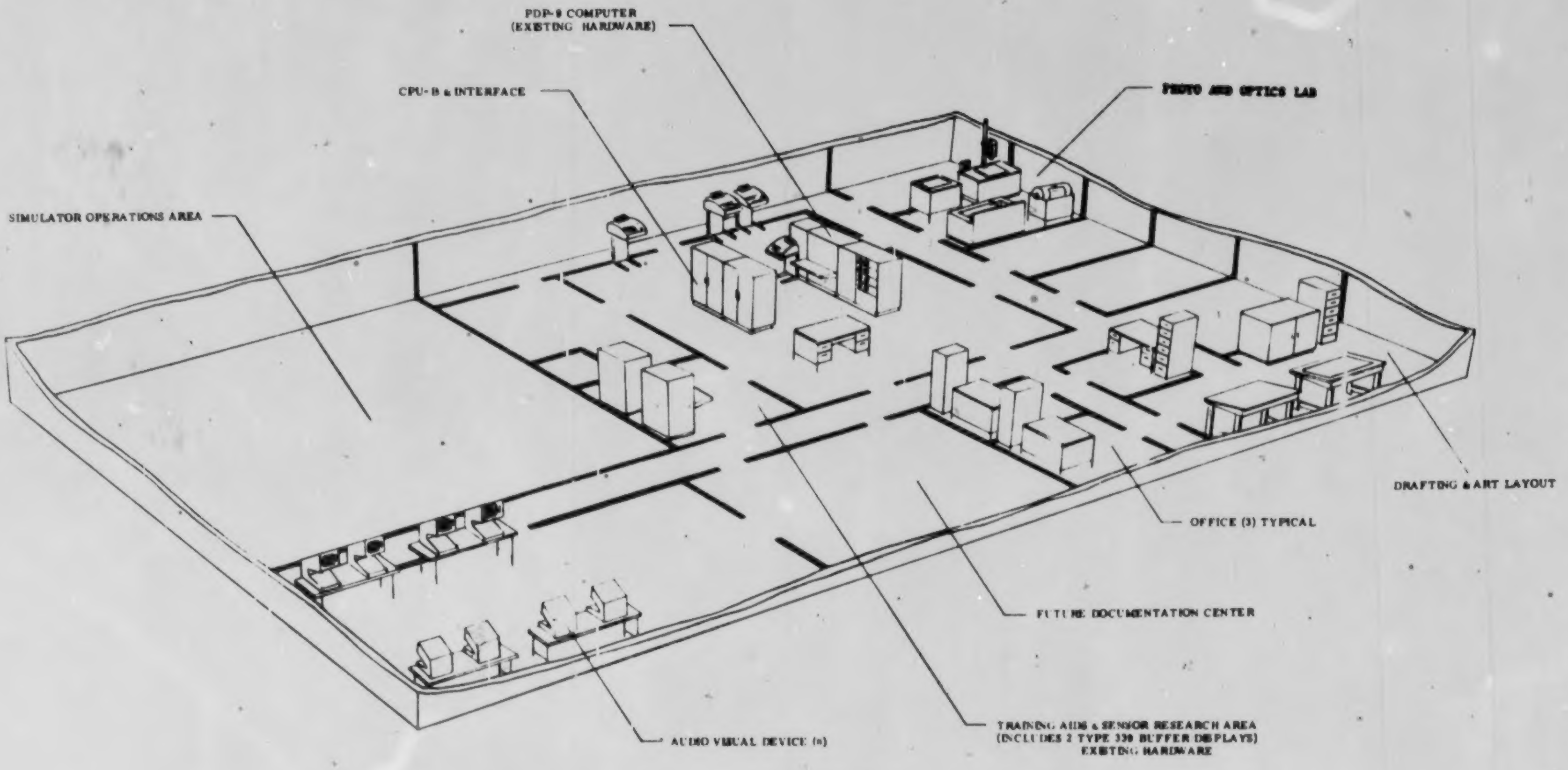
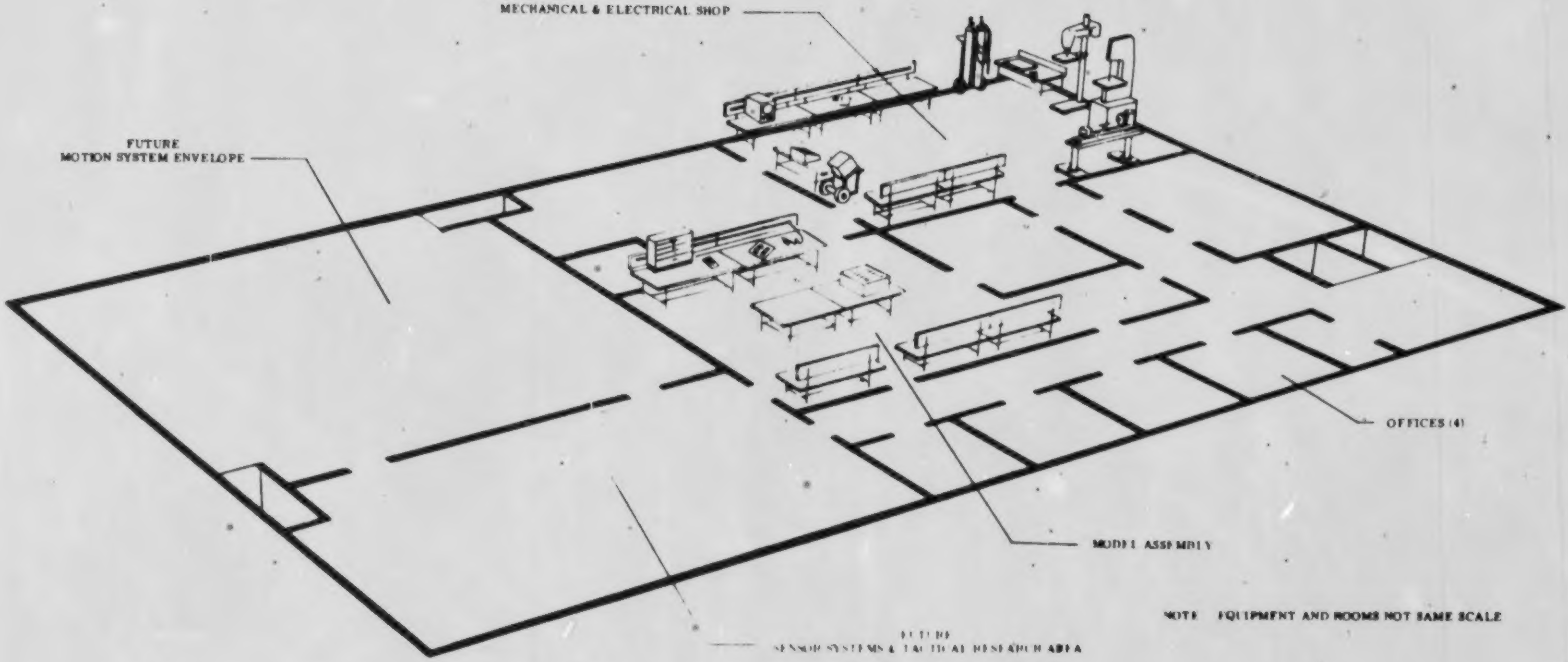

MECHANICAL & ELECTRICAL SHOP
FUTURE
MOTION SYSTEM ENVELOPE
OFFICES (4)
MODEL ASSEMBLY
FUTURE
SENSOR SYSTEMS & TACTICAL RESEARCH AREA
NOTE EQUIPMENT AND ROOMS NOT SAME SCALE

Figure 10. Module 1, Proposed Equipment Arrangement (Level 1)


PDP-9 COMPUTER
(EXISTING HARDWARE)
CPU-B & INTERFACE
PHOTO AND OPTICS LAB
SIMULATOR OPERATIONS AREA
DRAFTING & ART LAYOUT
OFFICE (3) TYPICAL
FUTURE DOCUMENTATION CENTER
TRAINING AIDS & SENSOR RESEARCH AREA
(INCLUDES 2 TYPE 339 BUFFER DISPLAYS)
EXISTING HARDWARE
AUDIO VISUAL DEVICE (8)

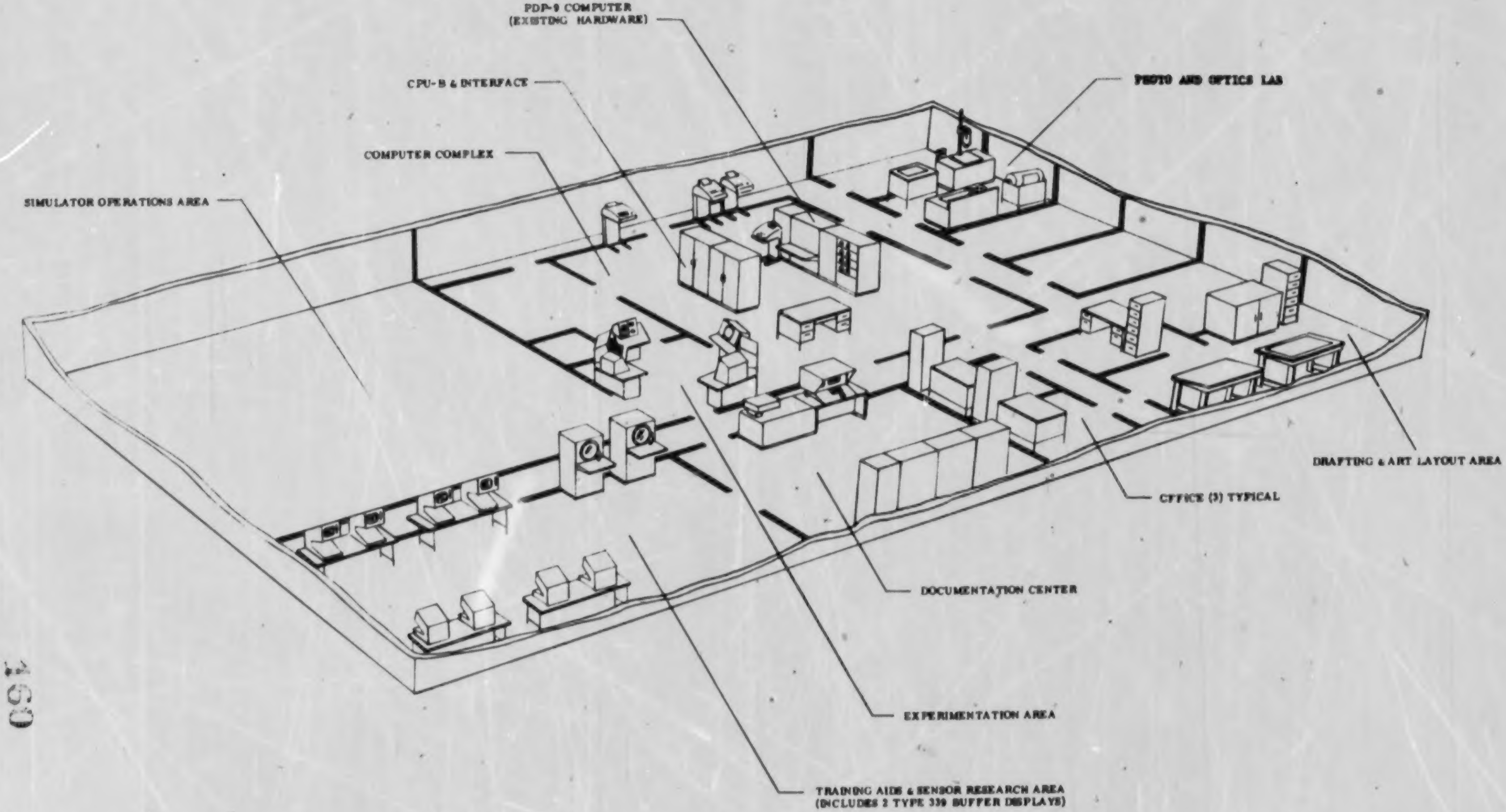
NOTE EQUIPMENT AND ROOMS NOT SAME SCALE

Figure 10. Module 1, Level 2 (Cont'd)


MECHANICAL & ELECTRICAL SHOP
FUTURE
MOTION SYSTEM ENVELOPE
OFFICES (4)
MODEL ASSEMBLY
FUTURE
SENSOR SYSTEMS & TACTICAL RESEARCH AREA

NOTE   EQUIPMENT AND ROOMS NOT SAME SCALE

Figure 11. Module 2, Proposed Equipment Arrangement (Level 1)


PDP-9 COMPUTER (EXISTING HARDWARE)
CPU-B & INTERFACE
PHOTO AND OPTICS LAB
COMPUTER COMPLEX
SIMULATOR OPERATIONS AREA
DRAFTING & ART LAYOUT AREA
OFFICE (3) TYPICAL
DOCUMENTATION CENTER
EXPERIMENTATION AREA
TRAINING AIDS & SENSOR RESEARCH AREA (INCLUDES 2 TYPE 339 BUFFER DISPLAYS)

NOTE: EQUIPMENT AND ROOMS NOT SAME SCALE

Figure 11. Module 2, Level 2 (Cont'd)

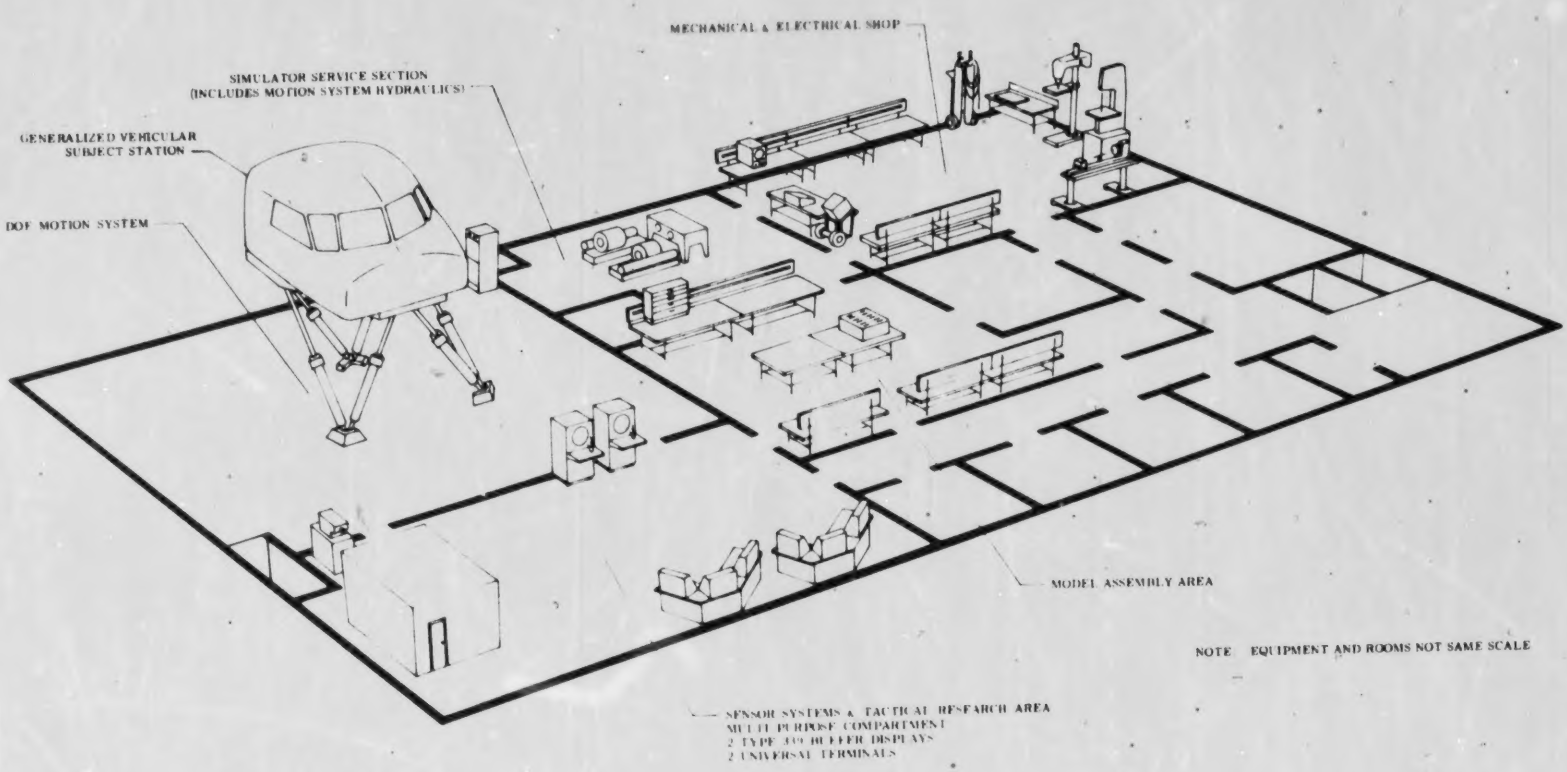
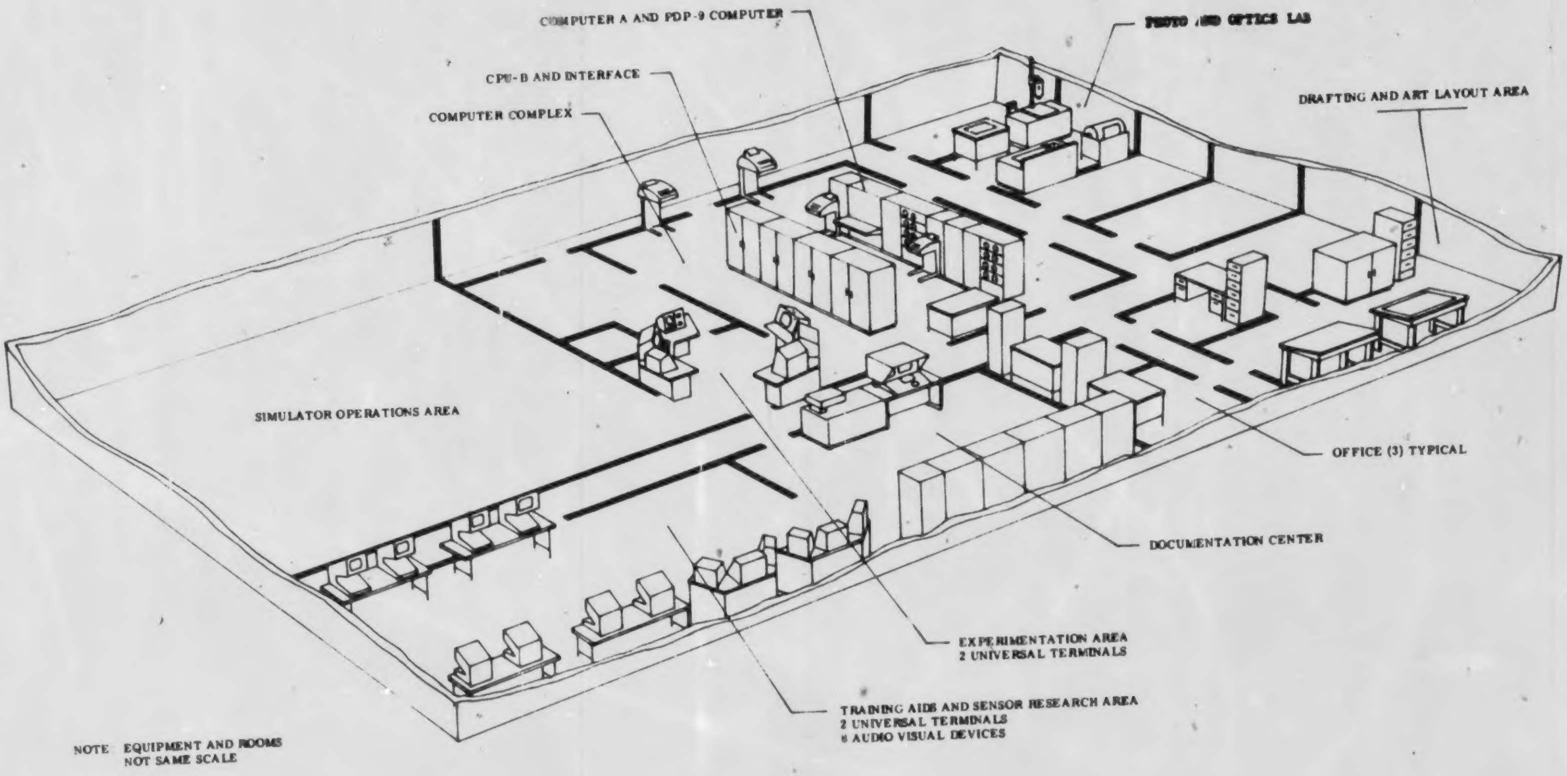

SIMULATOR SERVICE SECTION
(INCLUDES MOTION SYSTEM HYDRAULICS)
GENERALIZED VEHICULAR
SUBJECT STATION
6 DOF MOTION SYSTEM
MECHANICAL & ELECTRICAL SHOP
MODEL ASSEMBLY AREA
NOTE EQUIPMENT AND ROOMS NOT SAME SCALE
SENSOR SYSTEMS & TACTICAL RESEARCH AREA
MULTI PURPOSE COMPARTMENT
2 TYPE 340 BUFFER DISPLAYS
2 UNIVERSAL TERMINALS

Figure 12. Module 3, Proposed Equipment Arrangement (Level 1)


COMPUTER A AND PDP-9 COMPUTER
PHOTO AND OPTICS LAB
CPU-B AND INTERFACE
DRAFTING AND ART LAYOUT AREA
COMPUTER COMPLEX
SIMULATOR OPERATIONS AREA
OFFICE (3) TYPICAL
DOCUMENTATION CENTER
EXPERIMENTATION AREA
2 UNIVERSAL TERMINALS
TRAINING AIDS AND SENSOR RESEARCH AREA
2 UNIVERSAL TERMINALS
6 AUDIO VISUAL DEVICES
NOTE: EQUIPMENT AND ROOMS NOT SAME SCALE

MODULE 3 PROPOSED EQUIPMENT ARRANGEMENT
(SECOND LEVEL)

Figure 12. Module 3, Level 2 (Cont'd)

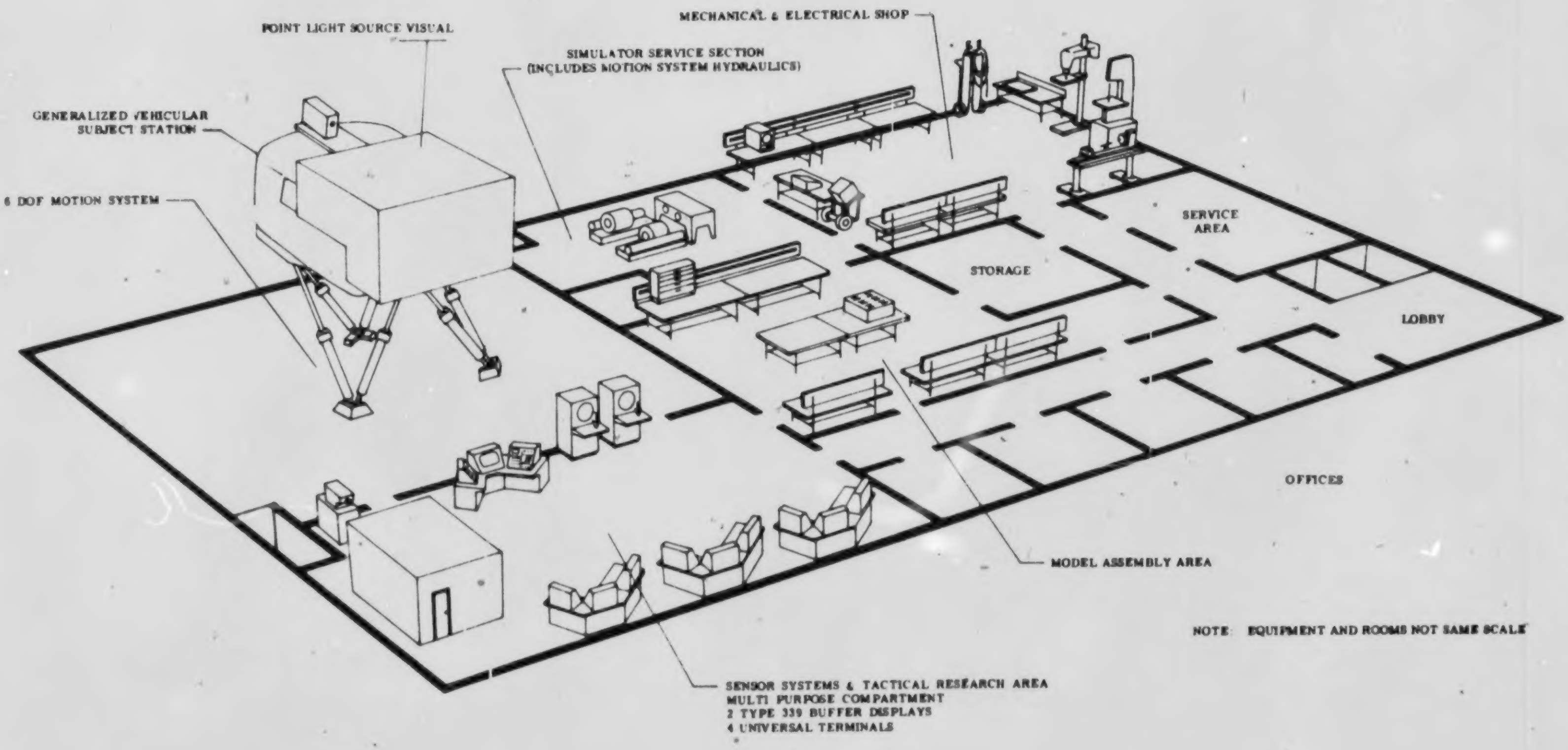
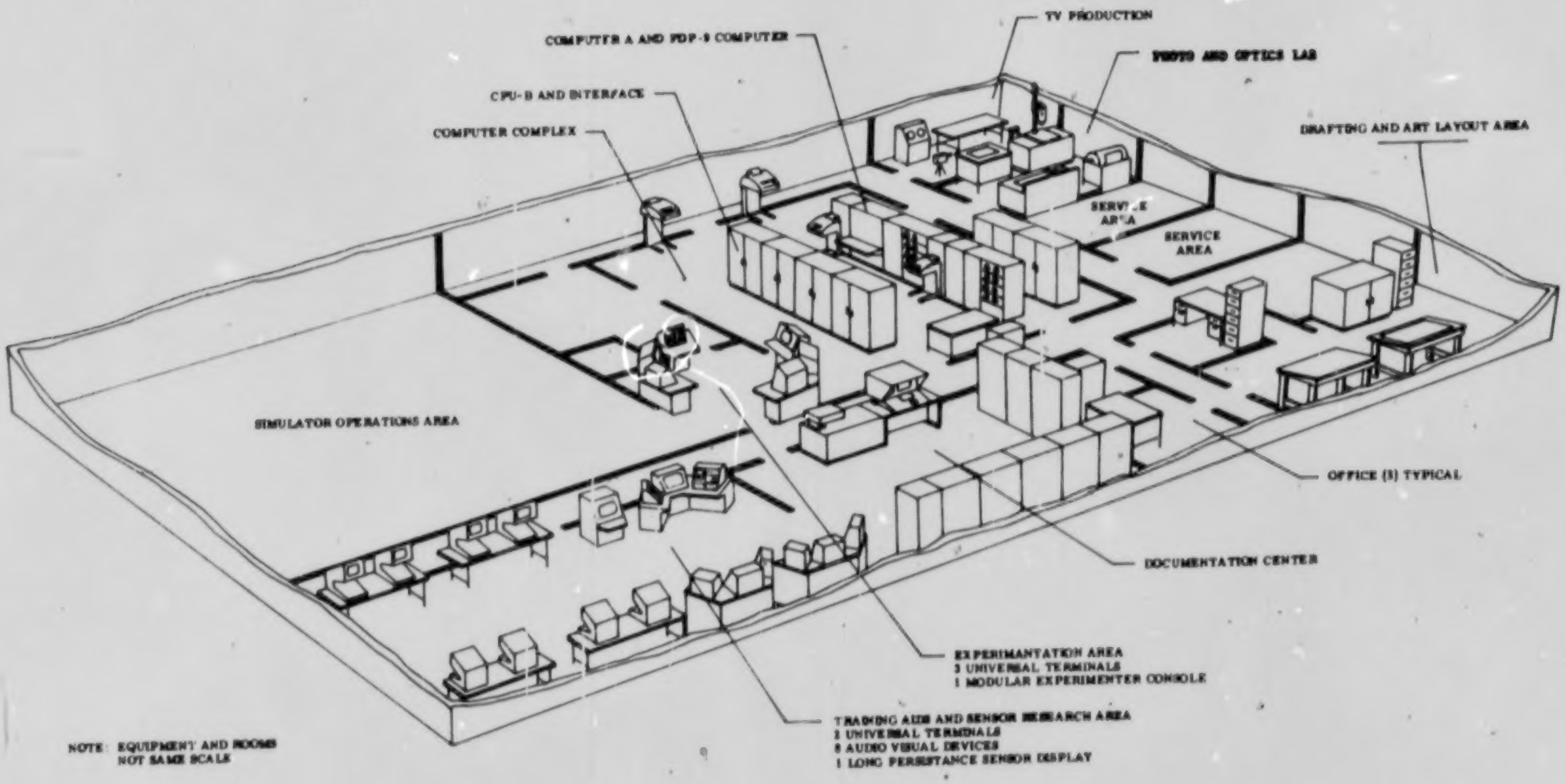
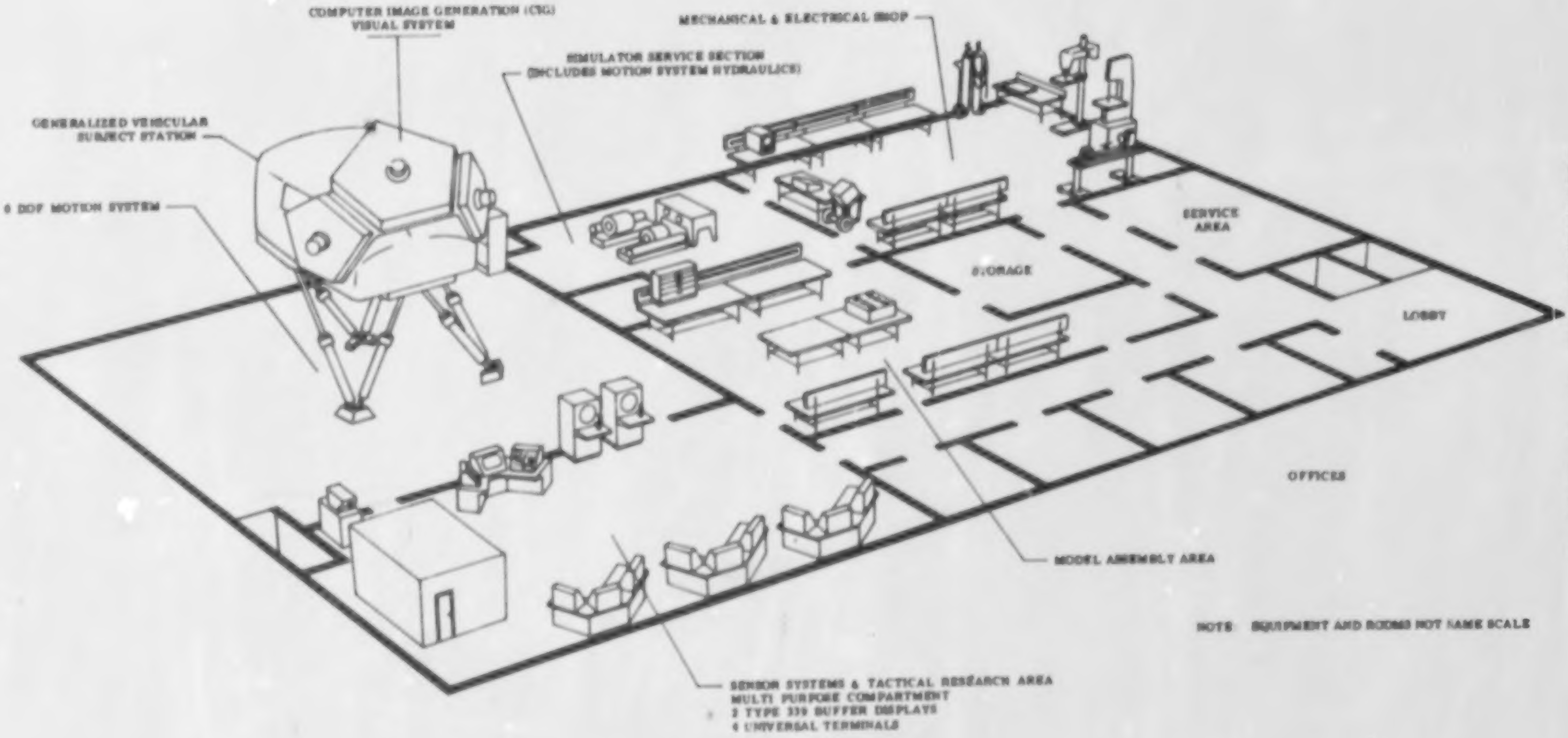

POINT LIGHT SOURCE VISUAL
GENERALIZED VEHICULAR SUBJECT STATION
6 DOF MOTION SYSTEM
SIMULATOR SERVICE SECTION (INCLUDES MOTION SYSTEM HYDRAULICS)
MECHANICAL & ELECTRICAL SHOP
SERVICE AREA
STORAGE
LOBBY
OFFICES
MODEL ASSEMBLY AREA
NOTE: EQUIPMENT AND ROOMS NOT SAME SCALE
SENSOR SYSTEMS & TACTICAL RESEARCH AREA
MULTI PURPOSE COMPARTMENT
2 TYPE 339 BUFFER DISPLAYS
4 UNIVERSAL TERMINALS

Figure 13. Module 4, Proposed Equipment Arrangement (Level 1)


COMPUTER A AND PDP-8 COMPUTER
CPU-B AND INTERFACE
COMPUTER COMPLEX
TV PRODUCTION
PHOTO AND OPTICS LAB
DRAFTING AND ART LAYOUT AREA
SERVICE AREA
SERVICE AREA
SIMULATOR OPERATIONS AREA
OFFICE (3) TYPICAL
DOCUMENTATION CENTER
EXPERIMANTATION AREA
3 UNIVERSAL TERMINALS
1 MODULAR EXPERIMENTER CONSOLE
TRAINING AIDS AND SENSOR RESEARCH AREA
2 UNIVERSAL TERMINALS
8 AUDIO VISUAL DEVICES
1 LONG PERSISTANCE SENSOR DISPLAY
NOTE: EQUIPMENT AND ROOMS
NOT SAME SCALE

MODULE 4 PROPOSED EQUIPMENT ARRANGEMENT
(SECOND LEVEL)

Figure 13. Module 4, Level 2 (Cont'd)


COMPUTER IMAGE GENERATION (CIG) VISUAL SYSTEM
MECHANICAL & ELECTRICAL SHOP
SIMULATOR SERVICE SECTION (INCLUDES MOTION SYSTEM HYDRAULICS)
GENERALIZED VEHICULAR SUBJECT STATION
6 DOF MOTION SYSTEM
SERVICE AREA
STORAGE
LOBBY
OFFICES
MODEL ASSEMBLY AREA
SENSOR SYSTEMS & TACTICAL RESEARCH AREA
MULTI PURPOSE COMPARTMENT
2 TYPE 339 BUFFER DISPLAYS
4 UNIVERSAL TERMINALS

NOTE: EQUIPMENT AND ROOMS NOT SAME SCALE

Figure 14. Module 5, Proposed Equipment Arrangement (Level 1)

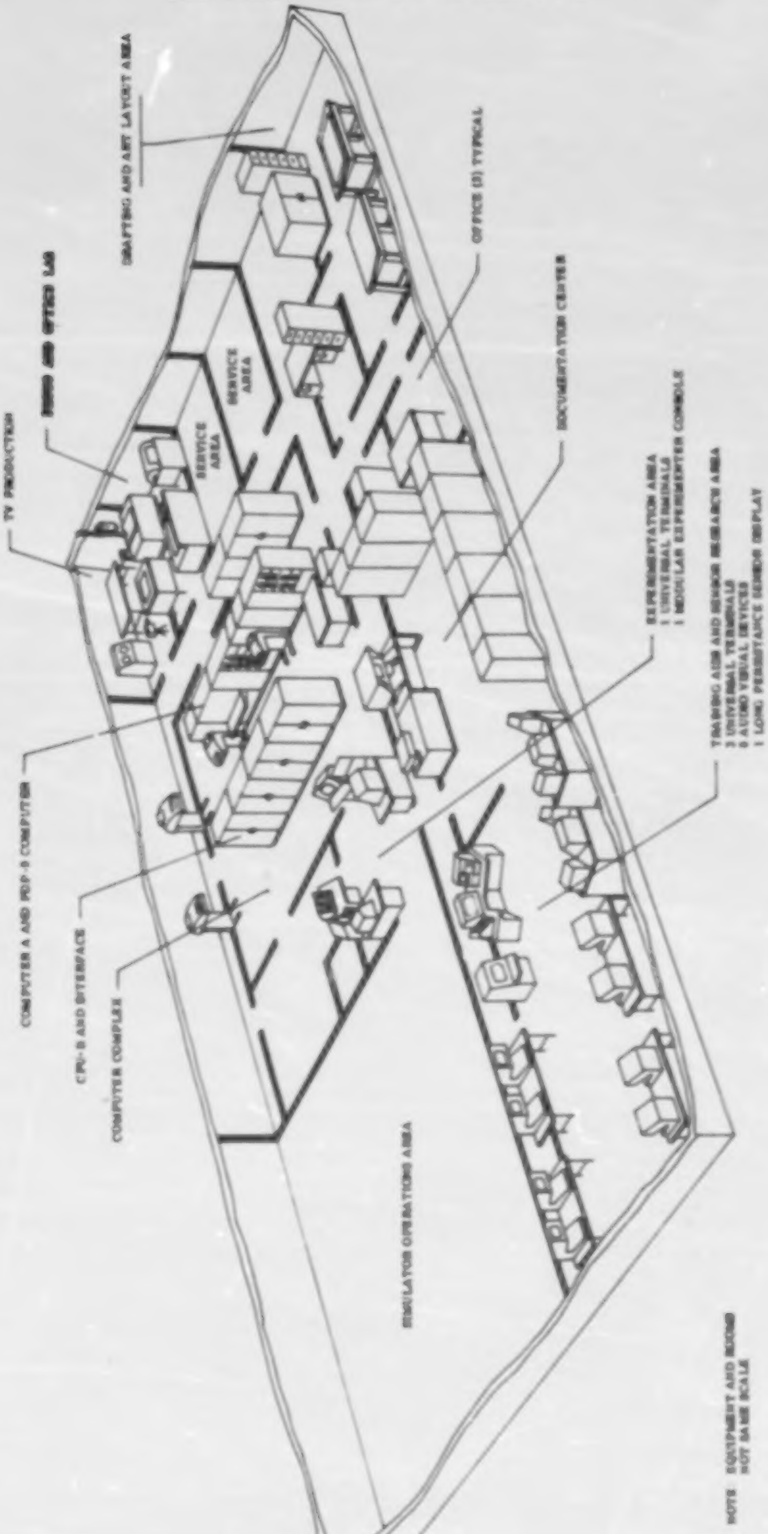

DRAFTING AND ART LAYOUT AREA
PHOTO AND OPTICS LAB
TV PRODUCTION
SERVICE AREA
SERVICE AREA
COMPUTER A AND PDP-8 COMPUTER
CPU-B AND INTERFACE
COMPUTER COMPLEX
SIMULATOR OPERATIONS AREA
OFFICE (3) TYPICAL
DOCUMENTATION CENTER
EXPERIMENTATION AREA
1 UNIVERSAL TERMINALS
1 MODULAR EXPERIMENTER CONSOLE
TRAINING AIDS AND SENSOR RESEARCH AREA
3 UNIVERSAL TERMINALS
6 AUDIO VISUAL DEVICES
1 LONG PERSISTANCE SENSOR DISPLAY
NOTE EQUIPMENT AND ROOMS NOT SAME SCALE

Figure 14. Module 5, Level 2 (Cont'd)

and experimental research functions of the facility; aids in the development of new procedures and evaluation of programs and equipment; provides guidance and direction to ETSS personnel, and is capable of performing work on the special peripheral terminals.

e. Secretary (Chief of Project Engineering) - General secretarial duties.

f. Clerical Filing Clerk - General operational duties associated with the documentation center; stores and retrieves tape files; catalogs tape files; conducts program for acquisition of reference material and scientific and technical publications in relevant fields; uses the special peripheral terminal for communication with the Central Computer Complex.

g. Computer Programmer and Keypunch Operator - Maintains the facility's software system; responsible for the executive system as well as operating programs; responsible for writing new programs; responsible for keypunching and verification of computer cards using related equipment; and uses the various communication devices to the computer.

h. Computer and Systems Operator - Provides assistance to the computer programmer; responsible for operation of computer equipment, peripheral equipment, development terminals and communication equipment; responsible for equipment and supplies for the complex; provides equipment checkout and assists in debugging; operates computer and peripheral equipment located within the CCC; uses the special peripheral terminal.

i. Visual Communication Technician - Responsible for audio-visual equipment including graphic, animation, TV production, recording and processing; and uses special peripheral terminal.

j. Photo-Lab Technician - Assists visual communication technician, and is responsible for photography and photodeveloping.

k. Electrical Technician - Provides technical services in electrical systems and works closely with the Model Shop; uses special peripheral terminal; conducts and fabricates tests of equipment; provides consultation services to entire facility.

l. Mechanical Technician - Aids in prefabrication of elements in Model Shop; provides consultation services to facility; participates in maintenance of hardware systems; and uses special peripheral terminal.

m. Electrical Maintenance Engineer - Provides general electrical maintenance services to the facility.

n. Mechanical Maintenance Engineer - Provides general mechanical maintenance to the facility.

o. Computer Maintenance Engineer* - Responsible for general maintenance of computer complex, video file and associated digital equipment of the facility.

p. Technical Editor-Typist - Self-explanatory.

14. HOUSING

A preliminary investigation of housing requirements for the ETSS facility indicated a need for a configuration that would permit housing the complete system. A design concept was developed to permit integration of system features and their relative support areas within a single building. It was recognized at the same time, that the facility might be procured in modules over an extended period of time. As a result, the building consists of modules that might be procured in such a manner.

14.1 SYSTEM ELEMENTS AND ASSOCIATED EQUIPMENT. An evaluation was made of the various system elements and their associated equipment to arrive at a preliminary estimate of floor space.

14.1.1 Documentation Center. The documentation center will house the following equipment: 1) two file sections, 2) four buffer sections, 3) ten tape sections, 4) one control section, 5) one or two special peripheral terminals and 6) a tape storage cabinet. Also required in support of this equipment are ancillary items such as desks, chairs, coat racks and other standard furniture. Allowing for maximum capability, the floor space and volume required for the documentation facility is:

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* Required if computer maintenance is not contracted from computer supplier.

Recommended Area = 750 square feet
Recommended Volume = 7500 cubic feet

14.1.2 Computer Complex. The computer complex will contain a multiple-CPU capability, linkage equipment, one tape controller, two tape drives, one PDP-9, mass storage device, I/O processor, disc controller, four teletypewriters and a special peripheral terminal. This equipment plus the allocation of personnel requires the following floor space and volume (the numbers are derived from Table 12 (Page 155)):

Recommended Area = 1350 square feet
Recommended Volume = 13500 cubic feet

14.1.3 Model Shop. The model shop will have capability for prefabrication of hardware associated with a particular experiment. The hardware designated for this task will be commercially available electromechanical equipment, including drill press, lathe, band saw, milling machine and an assortment of small power tools.

Recommended Area (includ. storage area) = 1500 square feet
Recommended Volume (includ. storage area) = 15000 cubic ft.

14.1.4 Training Aids Research. The training aids research area will employ a variety of equipment and configurations; the type of experimentation will determine specific hardware characteristics. The functions of this area will relate primarily to audio-visual and computer-aided instructional programs. The section will also have classroom-type capability and a communication link via the special peripheral terminal.

Recommended Area = 1075 square feet
Recommended Volume = 10750 cubic feet

14.1.5 Tactics, Sensor and System Research. This area will be able to be readily integrated with the vehicle simulator. Experimentation on radar, sonar and navigation systems will also be conducted. The section will contain a special peripheral terminal and equipment and simulation devices needed for tactical, sensor and system research.

Recommended Area = 1500 square feet
Recommended Volume = 15000 cubic feet

TABLE 12. COMPUTER SYSTEM INSTALLATION FIRST-ORDER COST ESTIMATES
(Courtesy of the Index Corporation)

	SIZE OF SYSTEM				UNIT
	SMALL	MEDIUM		LARGE	
System Cost (all hardware)	100,000	500,000	1,000,000	3,000,000	dollars
Estimated Floor Requirements	150	1,000	2,000	6,000	sq. feet
Auxiliary Service Floor	-	300	500	700	sq. feet
Air Conditioning for Space	-	3	5	15	tons
Power Consumption of Computer	2	10	20	60	kilowatts
Equivalent Heat Generated	7,000	35,000	70,000	210,000	BTU
Air Conditioning for Computer	0.6	3	6	18	tons
Total Air Conditioning	1	6	11	33	tons
Cost for Air Conditioning	500	3,000	5,000	12,000	dollars
Raised Floor	-	Laminated	Steel	Stringerless	type
Cost per Square Foot	-	3.50	4.50	5.50	dollars
Cost for Floor	-	3,500	9,000	33,000	dollars
Total Electrical Requirements	4	22	42	125	kilowatts
Service at 208 Volts	20	105	205	605	amperes
Electrical Installation	500	2,000	4,000	8,000	dollars
Supplies: Tapes (about $35)	50	100	200	1,000	reels
Disks ($12-$50/month)	20	30	50	100	packs
Supply Storage - Furniture	900	1,400	2,200	4,000	dollars

14.1.6 Experimental Design. The experimental design section's primary function will be orientation, design, guidance and dissemination of experiments to be performed. Three office areas are allocated for this function:

Recommended Area = 468 square feet
Recommended Volume = 4678 cubic feet

14.1.7 Vehicle Simulator. The motion system with cab and visual system calls for an operational envelope 40 feet in diameter and 30 feet high. Using the operational envelope as a basis for estimation, the following recommendations are made:

Recommended Area = 2500 square feet
Recommended Volume = 75000 cubic feet

14.2 SUPPORT ELEMENTS AND EQUIPMENT. To support the various experimental areas, research sections and environmental status of the building module, the additional facilities discussed herein are recommended.

14.2.1 Office Space. Four modular offices are needed for managing personnel and support personnel. Commercially available equipment will be used:

Recommended Area = 625 square feet
Recommended Volume = 6250 cubic feet

14.2.2 Service Areas. Service areas will contain commercially available lavatory equipment, four of which will be used in the facility:

Recommended Area = 988 square feet
Recommended Volume = 9887 cubic feet

14.2.3 Simulator Service Area. The simulator service area will contain the hydraulic pumps and other associated hardware:

Recommended Area = 950 square feet
Recommended Volume = 9500 cubic feet

14.2.4 Mechanical Section. The mechanical section will house all motors, generators, heating and air-conditioning equipment:

Recommended Area = 1200 square feet
Recommended Volume = 12000 cubic feet

14.2.5 Lecture and Conference Room. This section will contain the equipment necessary to carry on classroom-type lectures and conferences; it is recommended that it also have a full A-V capability:

Recommended Area = 443 square feet
Recommended Volume = 4437 cubic feet

14.2.6 Storage Areas. Normal storage rooms are recommended:

Recommended Area = 462 square feet
Recommended Volume = 4625 cubic feet

14.2.7 Freight Elevator. One freight elevator with capacity no less than 4000 pounds is recommended to provide service to the facility:

Recommended Area = 100 square feet

14.2.8 Television Production Laboratory. To provide an in-house capability for television production of lectures, experiments, etc., a TV laboratory is recommended. Equipment contained in the room will include lighting, camera, receiver and recording equipment:

Recommended Area = 218 square feet
Recommended Volume = 2187 cubic feet

14.3 LOGISTIC REQUIREMENTS. To provide for transportation of elements, maintenance and capability among system features, the areas designated for the various research sections must be designed to minimize logistical problems. After inspection of the various system elements and their relationships, it was determined that the optimum configuration would be a three-story facility.

The recommended space volume plan is given in Table 13 (Page 158). It takes into account the problems of logistics and system integration.

TABLE 13. RECOMMENDED FLOOR PLANS

	ESTIMATED AREA (Sq. Ft.)	VOLUME (Cu. Ft.)
First Floor Area and Volume		
(1) Simulator Operations Area	2,500	75,000
(1) Sensor, System, Tactics, Research	1,500	15,000
(1) Simulator Service Area	950	9,500
(1) Mechanical Section	1,200	12,000
(1) Model Shop (incl. storage)	1,500	15,000
(2) Service Areas	525	5,250
(4) Office Areas	625	6,250
TOTAL USABLE AREA AND VOLUME	8,800	138,000
TOTAL FIRST FLOOR AREA	10,000 sq. ft.	
Second Floor Area and Volume		
(1) Training Aids Research	1,075	10,750
(1) TV Production Area	218	2,187
(1) Documentation Center	750	7,500
(1) Photo and Optics Lab	218	2,187
(3) Office Areas	468	4,687
(1) Lecture and Conference Room	443	4,437
(2) Service Areas	393	3,937
(1) Storage Area	400	4,000
(1) Experimenter's Area	400	4,000
(1) Computer Complex	1,350	13,500
TOTAL USABLE AREA AND VOLUME	5,718	57,187
TOTAL SECOND FLOOR AREA	7,500 sq. ft.	
Third Floor Area and Volume		
Simulator Operations Area	(included in First Floor estimate)	

TOTALS: Total Usable Area = 14,518 square feet
Total Building Volume = 225,000 cubic feet

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14.4 ARCHITECTURAL REQUIREMENTS. The architectural requirements will be standard requirements for similar facilities consistent with manning and equipment recommended by this study.

14.4.1 Room Size. Room sizes for the system elements and their support functions depend principally on the activity and equipment associated within each room. All designated areas are center-to-center, based on single line drawings. The rooms are completely enclosed with floor-to-ceiling partitions and doors that facilitate freedom of movement, use of portable equipment and accommodation of personnel. Walls, floor and ceilings are to be equipped with sound-absorbing material to minimize distraction for those involved in experiments.

14.4.2 Hallways. Main hallways will be at least 6 feet wide; hallways within research areas will be a minimum of 4 feet wide to facilitate movement of equipment and personnel.

14.4.3 Doorways. Standard doors are at least 4 feet wide to allow for movement of equipment and furniture in and out of rooms. Doors are allocated to ensure easy access to areas within the complex.

14.4.4 Walls. Standard walls are assumed except in areas where special precautions are exercised to ensure reduction in noise levels.

14.4.5 Ceiling. A minimum clear ceiling height of 120 inches is recommended in work areas other than the simulator operations room, where a 30 foot ceiling is necessary. These estimates include proper height for electronic installations, lighting and heating ducts.

14.5 STRUCTURAL REQUIREMENTS.

14.5.1 Flooring. Heavy equipment such as mechanical pumps and heating elements will be located on the first floor. False flooring is recommended where cabling is required as in the computer complex.

14.5.2 Overhead Hoist. An overhead hoist located in the simulator operations area is recommended. It should have the capacity of supporting and hoisting simulator elements such as the cab, visual system components and other hardware.

14.6 MECHANICAL REQUIREMENTS.

14.6.1 Cooling Air. Cooling air will be provided for equipment cooling and personnel comfort. The system recommended includes the following:

a. Computer Room - High and low temperature alarms are recommended to provide a safety limit subject to specific equipment needs.

b. Work Areas - Temperature controls to ensure proper environmental conditions.

c. Documentation Center - Control of temperature to ensure equipment operational safety limits.

d. Experimenter Station - Temperature control to ensure proper level of safety for equipment.

e. Photo and Optics Lab - Temperature control to ensure operational status.

f. TV Production Lab - Optimum cooling with temperature control.

14.6.2 Fire Protection and Equipment. A fire warning system is recommended, each room and hallway having an alarm connected to a master alarm panel. Each room will be equipped with an extinguisher for fighting electrical fires.

14.6.3 Elevators. One freight elevator is recommended for the facility; it should be at least 8 feet square and have a capacity not less than 4000 pounds.

14.6.4 Lavatories. Lavatories are designated in four service areas, which should be adequate for the facility.

14.6.5 Filtering. Normal air-filtering techniques are recommended.

14.6.6 Inter-Facility Communication. Commercially available telephone and public address systems are recommended.

14.7 ELECTRICAL REQUIREMENTS.

14.7.1 Power Supply. The facility power needs will be based on equipment consumption rates. Standard commercial power, 120-208 volts ± 10%, 60 Hz ± 5% is recommended.

14.7.2 Lighting. Commercially available overhead lighting with dimming control is recommended for research areas. Other areas will be supplied with standard lighting and control.

14.7.3 Convenience Outlets. Convenience outlets are recommended for each room with the number of outlets to be compatible with the respective room activity.

14.7.4 Grounding. Grounding will be normal except where specified by equipment needs or manufacturer's specifications.

15. MANAGEMENT APPROACH

No matter how efficient the design and implementation of the ETSS or how high the competence of its technical personnel, if the facility is not used properly the objectives will not be fulfilled. This study was not aimed at developing a management approach for the ETSS, but it was felt that some mention should be made of this important aspect of the ETSS utilization plan.

One of the areas most often overlooked in facility planning is communications. Each member of the ETSS, particularly the human factors psychologists, should be kept aware of the results and implications of each experiment. This can be accomplished by using the Videofile documentation system.

Another area that should be of concern in ETSS planning is that of management authority. During experimentation, the experimenter, i.e., the human factors psychologists must have complete managerial control over all interfacing systems of the ETSS.

Since the scheduling of work and experiments can become a serious burden to the people involved in a system such as the ETSS, and since the very nature of some of the experiments (e.g., adaptive training) does not permit rigid scheduling, an automated, flexible system that would enable rapid rescheduling, is highly recommended for the ETSS facility.

16. EXPERIMENTAL DESIGN AND IMPLEMENTATION

The work performed by the ETSS will be governed by requests for "research in training approaches" received by the Human Factors Laboratory (HFL) from the Naval Training Device Center, and will be further influenced by results of previous in-house research and HFL needs. Efficient use of the ETSS will rely to a large extent on smooth scheduling of in-house or subcontracted activities.

A request for experimental data will generally result in a meeting between the ETSS director and ETSS psychologists. A Videofile search will be made to determine if previous data or information which could satisfy the requirement exists. According to the workload of project psychologists, the director may assign one responsibility for providing the desired information. Generally, this assignment will result in performance of an experiment.

The project psychologist will analyze the training requirements and determine which services of the ETSS are required. A PERT chart would then be prepared, illustrating all services required to bring the components of the experiment together. The services that may be considered are:

- CAI (training aids)
- Sensor research area
- System research area
  - Motion
  - Visual
  - Sound
- Programming support
- Videofile services
- Universal terminal availability
- Computer availability
- Model shop scheduling
- Photo lab scheduling
- Experimenter station
- External services
- Availability of subjects

It is the responsibility of the delegated project psychologist to ensure that the various services are scheduled so that the experiment may be performed at the required time. It is also the responsibility of the project psychologist to file any documentation pertaining to the experiment in the Videofile system.

When support services have either performed their work or are waiting for the experiment to run, human subjects will be called in to perform the experiment. It will be the responsibility of the project psychologist to ensure that the subjects are suitably briefed about the nature of the experiment beforehand.

When the experiment is over, the gathered data will be analyzed, formatted and incorporated into a report. This report will include the procedures involved in setting up the experiment, assumptions, definition of special programs, materials used and results of the experiment. The report will be filed in the Videofile data storage system and special programs will be filed on magnetic tape. Copies of the final report will be sent to the requesting agency and abstracts to the cognizant Navy personnel.

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APPENDIX A

PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

This appendix summarizes in tabular format the various operational requirements of military vehicular systems, the functions of personnel in operating them, the skills and knowledge required by these personnel and the specific implications that these have on training programs.

The major operator tasks unique to each of the four types of systems supported by the Naval Training Device Center were listed and briefly described. The content of training, and the general implications for optimum training settings were identified for each task. These data were then reviewed across systems to identify areas of commonality among learning functions and potential training situations. Table 1 (Page 74) is a summary of categories of tasks accumulated from Table 14 (Pages A-2 to A-13). This accumulation was used to define the basic characteristics of the equipment required to support experiments in learning settings relevant to each category.

TABLE 14. PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
1.0 SUBMARINE OPERATIONS				a Familiarization with operating theory.
1.1 Diving, Hovering, Maneuvering, Surfacing	1.1.1 Establishment of present and desired positions, speed, depth rate and heading. 1.1.2 Derivation of control positions and actions required in achieving desired position, speed, depth, depth rate and heading. 1.1.3 Control of planes, helm, power, ballast and vent systems to achieve desired position, speed, heading, depth, dive/ascent angle and rate.	a Helm, plane, ballast, vent and propulsion system operating procedures. b Basic submarine diving, hovering and steering dynamics. c Communications procedures.	a Coordination of depth, depth rate, ballast, vent, and plane position data with knowledge of diving dynamics in development of control output requirements. b Timing of control inputs to lead desired depth rate, depth, heading.	b Practice required in operating and communication procedures. c Practice required in tracking displays of depth, depth rate, plane position, heading. d Practice required in integrating knowledge of submarine buoyancy, diving and maneuvering dynamics in controlling position and path.
1.2 Sonar Operation	1.2.1 Sonar system operating and checkout procedures. 1.2.2 Classification of sonar targets. 1.2.3 Classification of sound sources. 1.2.4 Determination of target range bearing, speed and aspect angle. 1.2.5 Maintenance of sonar security.	a System operating procedures. b Sonar operating theory. (1) Effects of bottom, temperature density on sonar signal propagation. (2) Sound characteristics of potential targets. (3) Sound characteristics of biological sources. (4) Operating SOP's c Tactical employment of sonar in maneuvering, attack, security.	a Tuning of aural and visual displays to facilitate target classification. b Perception of aural and visual display data differentiating targets and target characteristics. c Interpretation of environmental effects data in analysis of aural and visual data on target classification, location, speed, bearing and aspect angle. d Analysis of aural and visual data in defining nature of environmental effects and sound behavior.	a Familiarization with operating theory and procedures. b Practice in operating procedures. c Observation of effects of controls on passive, active signals. d Observation and differentiation of effects of environmental conditions on target sounds and reflectances. e Analysis of target characteristics, differences.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
1.2 (Cont'd.)		d Mission requirements. e Communications procedures. f Standing operating procedures.		f Observation and differentiation of effects of biological sound sources. g Practice in classification of possible active targets under various environmental conditions.
1.3 Radar Operation	1.3.1 Radar system operating and checkout procedures. 1.3.2 Radar target identification. 1.3.3 Determination of target range, bearing, heading, speed, altitude. 1.3.4 Interpretation of weather, other environmental effects on radar image. 1.3.5 Interpretation of effects of jamming. 1.3.6 Maintenance of radar security.	a System operating procedures. b Radar operating theory. (1) Correlation of radar characteristics with displayed information. (2) Correlation of target characteristics with displayed information. (3) Effects of controls on display performance. (4) Environmental effects on radar performance. c Mission requirements. d Communications procedures. e SOP's	a Selection and employment of normal, emergency operating procedures. b. Adjustment of displays for enhancement of target characteristics. c Analysis of displayed information for data on target type, range, bearing, attitude, heading and speed. d Discrimination of targets in voice and jamming. e Selection and employment of anti-jam techniques.	a Familiarization with operating theory and procedures. b Practice in operating and checkout procedures. c Practice in perception of targets in noise, chatter and jamming. d Practice in perception of effects of controls, environmental influences.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
1.4 Propulsion and System Management	1.4.1 Maintain propulsion auxiliary life support systems in operation. 1.4.2 Diagnose problems in system operation and status. 1.4.3 Select and employ alternate operating modes. 1.4.4 Control system operations as required by mission tasks. 1.4.5 Correlate systems operation with relevant environmental conditions.	a Operating theory and procedures. b Mission functional requirements. c Mission environment. d Communications procedures. e Standing operating procedures.	a Interpret system displays, submarine performance, commands in defining control actions. b Coordinate control and command outputs to provide propulsion and system outputs as required by mission; account for effects of environment, enemy action, tactical considerations in control or propulsion, auxiliary and life-support systems.	a Familiarization with systems operating theory and procedures. b Practice in interpretation of system status, and in the selection of normal and degraded operating modes. c Practice in execution of normal and degraded mode procedures in representative mission, tactical and environmental contexts. d Practice in communications.
1.5 Periscope Operation	1.5.1 Operate periscope extension, retraction, focus, magnification, varying controls to place periscope in operation and to stow it. 1.5.2 Employ periscope in determination of range, bearing, speed and heading of surface targets. 1.5.3 Maximum security during periscope operations.	a Periscope operating procedures. b Standing operating procedures. c Mission function requirements. d Mission environment. e Target identifying features.	a Stadimetric ranging. b Telemetric ranging. c Correlation of radar, sonar reports with periscope data on target location, motion. d Estimation of target speed and heading. e Extrapolation of target future position, bearing and heading.	a. Familiarization with operating, ranging procedures. b Familiarization with target characteristics. c Practice in perception of targets in various conditions of lighting, visibility and aspect. d Practice in target tracking and target speed, heading estimation. e Practice in plotting target relative position and motion.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
1.6 Navigation	1.6.1 Identify present position through dead reckoning, contact, radio, electronic inertial techniques. 1.6.2 Pilot course to desired position. 1.6.3 Establish speed, heading required to reach desired position at desired time. 1.6.4 Operate radio, electronic and inertial navigation system controls to make good desired position; take celestial navigation fixes. 1.6.5 Reconcile data among different navigation modes and systems. 1.6.6 Select navigation modes appropriate to mission, environment and system status constraints.	a Principles of dead reckoning, radio, electronic, contact, celestial inertial navigation. b Limitations and capabilities of navigation modes and systems. c Tactical and environmental effects on each navigation mode, system and technique. d Position and course plotting techniques. e Procedures required in operating, checking out, aligning and evaluating navigation systems and equipment.	a Interpretation of position, speed and heading data from various sources. b Selection of navigation modes and systems compatible with mission, tactical and security requirements. c Modification of navigational mode to account for variations in mission requirements and changes in navigation systems and environmental status.	a Familiarization with procedures required in contact, radio, electronic celestial, inertial navigation. b Familiarization with effects of mission environment, tactics, on navigation system capabilities. c Practice in selection, utilization of available navigational procedures. d Exposure to interrelations of tactics, mission, environment, navigation mode; practice in modifying mode of operation to account for varying directions.
1.7 Target Detection/ Acquisition	1.7.1 Operate periscope, radar, sonar systems to detect potential targets. 1.7.2 Evaluate sensor data for target type, position, speed, heading, threat. 1.7.3 Pilot target position; maintain data on position, heading speed and threat status. 1.7.4 Predict target position, heading, speed, based on minimal data.	a Sensor operating procedures. b Characteristics of potential targets (visual, sonar, radar). c Position plotting procedures. d Communications. e Environmental effects on sensor data.	a Perception and extrapolation of target motion to predict future position. b Perception of relevant target characteristics in various basic environments; discrimination of target types. c Evaluation of data from various sensor modes and systems.	a Familiarization with types of data provided by sensor systems, effects of environment, mission and tactics on quality of sensor data. b Practice in interpretation of target data in representative environments and operating modes.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
1.7 (Cont'd.)			d Selection of sensor operating modes to enhance target acquisition probability.	
1.8 Weapon Selection, Checkout, Aiming, Adjustment, Arming, Launch	1.8.1 Identify weapon effect required by mission, tactics and environment. 1.8.2 Evaluate weapon alternatives. 1.8.3 Select weapon and delivery mode compatible with mission requirements, weapon status, tactics, target characteristics and environmental constraints. 1.8.4 Establish weapon/target intercept point and time. 1.8.5 Range/align/adjust weapon for required trajectory to target. 1.8.6 Identify and attain launch position; launch weapon. 1.8.7 Sense and evaluate weapon effect for subsequent launch.	a weapon capabilities. b Mission requirements. c Environmental effects on weapon employment. d Tactical effects on weapon employment. e Weapon selection, checkout, aiming adjustment, alignment, arming and launch procedures. f Maneuvering procedures.	a Integration of data on target relative position and motion, weapon characteristics and own-ship motion and position to define weapon launch time and parameters. b Evaluation of mission, tactics, enemy and environmental data in selection of targets and of attack weapon and launch modes. c Coordinate own-ship speed, heading with weapon/target calculations.	a Familiarization with weapon characteristics and procedures. b Familiarization with target attack modes, tactical, environmental influences on attack modes. c Familiarization with target/weapon plotting procedures. d Practice in target approach and weapon control in various tactical, physical and mission environments. e Practice in weapon sensing and application of sensed data in subsequent launches.
1.9 Close-in Maneuvering and Docking	1.9.1 Control submarine speed and heading to take up desired position with respect to fixed or moving reference. 1.9.1.1 Sense own-ship/reference relative bearing, motion.	a Submarine surface dynamics. b Communications procedures.	a Perception of relative motion. b Correlation of engine and helm commands with submarine motion.	a Familiarization with submarine maneuvering dynamics. b Practice in generation and execution of engine and helm commands in relation to fixed and moving reference points.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
1.9 (Cont'd.)	1.9.1.2 Derive engine and helm commands to produce desired speed/heading/position. 1.9.1.3 Continuously evaluate relative position, motion; modify engine and helm commands as required.			
1.10 Emergency Escape, Damage Capability Control Operations	1.10.1 Recognize emergency conditions. 1.10.2 Perform appropriate emergency procedures during time and environmental stress.	a Normal/abnormal system operating characteristics. b Standard emergency, escape, rescue, damage and casualty control procedures. c Effects of tactical, physical environment on procedures.	a Recognition of emergency conditions. b Selection of procedures appropriate to conditions and environmental limitations. c Performance of emergency procedures under extreme stress.	a Familiarization with emergency procedures and with escape, rescue, damage and casualty control procedures. b Familiarization with effects of tactical, physical environment on performance of procedures. c Practice in relevant procedures in representative stresses.
2.0 SURFACE SHIP OPERATIONS	(Similar to submarine-related tasks, with the exception of diving, hovering and surfacing, and underwater rescue.)			

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
3.0 LAND SYSTEM OPERATION				
3.1 Operate Tracked/Wheeled Vehicles	3.1.1 Perform checkout and engine start procedures; checkout and operate vehicle systems.	a Vehicle checkout and systems operating procedures.	a Diagnosis of vehicle and vehicle system status.	a Familiarization with vehicle and systems checkout, operating and diagnostic procedures.
	3.1.2 Use transmission and power controls to move vehicle forward and in range.	b Vehicle/terrain dynamics.	b Correlation of terrain with vehicle capabilities.	b Familiarization with vehicle/terrain dynamics.
	3.1.3 Use transmission, power and steering controls to move vehicle along prescribed ground path, forward and in reverse.	c Principles of tactical movement.	c Correlation of map and terrain in route selection with tactical, mission, mobility, security constraints.	c Familiarization with appropriate tactical/navigation concepts and systems.
	3.1.4 Maneuver over various types and conditions of terrain; i.e., rough, muddy, icy, etc.	d Map-reading, navigation procedures.	d Maneuvering in varying terrain and visibility conditions.	d Practice in vehicle and systems checkout, operation and diagnosis.
	3.1.5 Drive in convoy and tactical formations.	e Communications procedures.	e Close-in maneuvering and obstacle avoidance.	e Practice in maneuvering in convoy and formation over various terrain types in unlimited and limited visibility.
	3.1.6 Maneuver in proximity to obstacles and terrain features.	f Formation driving principles and procedures.	f Convoy and formation driving in unlimited and limited visibility.	f Practice in route selection and utilization.
	3.1.7 Select routes to satisfy mission, tactical and mobility constraints.	g. Mission requirements.	g Interpretation of radar, CCTV, IR, LLLTV systems.	g Practice in route reconnaissance and surveillance.
	3.1.8 Perform landmark, electronic navigation functions.	h Escape and rescue procedures.	h Route evaluation and surveillance for mobility and tactical implications.	h Practice in operation and interpretation aids to vision.
	3.1.9 Perform tactical surveillance functions along route.	i Operating principles and procedures for special visual aids.	i Route selection.	i Practice in navigation system utilization.
	3.1.10 Perform communications functions.	j Traffic regulations.	j Performance of escape and rescue procedures under stress.	j Practice in escape and rescue in stressful environments.
	3.1.11 Employment of special vision devices.			
	3.1.12 Escape and rescue operations.			

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
3.2 Air-Cushion Vehicles	3.2.1 Task requirements similar to those in tracked and wheeled vehicles, except: 3.2.1.1 Maneuvering on slopes. 3.2.1.2 Maneuvering in wind. 3.2.1.3 Obstacle clearance. 3.2.1.4 High speed operation over water and land.	a Air-cushion vehicle operating principles, dynamics and procedures. b Unique tactical capabilities of air-cushion vehicles. c Maritime rules of the road.	a Allowance for wind and slope effects on groundtrack. b Allowance for wind and slope effects on turning capabilities. c Evaluation of route for vehicle compatibility.	a Familiarization with air-cushion vehicle characteristics and capabilities. b Practice in operations in various slopes, obstacles, and wind conditions.
3.3 Individual Military Skills	3.3.1 Operation of individual equipment and weapons. 3.3.2 Patrolling and navigation. 3.3.3 Target, landmark detection and interpretation. 3.3.4 Small unit tactics.	a Principles of equipment operation. b Principles of navigation, military organization, tactics. c Individual and small unit security.	a Individual marksmanship b Map reading, use of compass and landmarks, both day and night c Employment of individual weapons and equipment in defensive, offensive operations.	a Familiarization with principles of individual and small unit operations and tactics. b Practice in individual skills. c Practice in small unit skills.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
4.0 AIRCRAFT				
4.1 Aircraft/ Systems Procedures	4.1.1 Perform checkout and engine start procedures; checkout and operate aircraft systems.	a Normal and alternate aircraft systems operating procedures. b System operating characteristics and dynamics. c Environmental influences on system operation.	a Aircraft system operating procedures. b Analysis of environmental effects on system operation.	4.0 a Familiarization with aircraft/systems operating procedures. b Familiarization with environmental effects on aircraft and systems. c Practice in control of aircraft by reference to visual and instrument indications. d Practice in control of aircraft in low-level, high-speed flight. e Practice in takeoff and landing on prepared/ unprepared sites, in unlimited and limited visibility.
4.2 Aircraft Control	4.2.1 Use engine/propeller/rotor, ground steering controls to move aircraft. 4.2.2 Select takeoff position and direction. 4.2.3 Use engine/propeller/rotor, directional controls to accomplish takeoff. 4.2.4 Maintain aircraft in straight and level flight. 4.2.5 Select desired ground track and altitude; control aircraft to make good desired ground track and altitude. 4.2.6 Control aircraft in low-level flight; maintain minimum clearance from terrain. 4.2.7 Control aircraft in formation flight to maintain relative position with respect to other aircraft.	a Effects of aircraft flight and power controls b Wind, weight, temperature, surface effects on aircraft performance. c Communications procedures. d Traffic regulations. e Unit operational and tactical SOP's.	a Coordinate power/rotor/ propeller/heading controls to move aircraft over surface. b Assess effects of wind, load, surface condition on takeoff performance. c Coordinate flight and and power controls to achieve takeoff. d Coordinate flight and power controls to maintain straight and level flight at desired heading, altitude, airspeed. e Recognize elevation above terrain, in low-level, high-speed flight. f Estimate flight path angle required to maintain desired terrain clearance.	

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
4.2 (Cont'd)	4.2.8 Execute approach to landing site; execute landing.		g Maintain aircraft within safe altitude and acceleration envelope in following terrain contours. h Estimate requirements for heading vs. altitude changes in terrain following, terrain avoidance. i Maintain geographic orientation in low-level, high-speed terrain avoidance, terrain following flight. j Estimate distance, bearing and relative velocity of aircraft with respect to other aircraft in formation. k Coordinate flight, power, trim controls to maintain safe relative distance, velocity with respect to lead aircraft in formation flight. l Estimate relative position, velocity and bearing with respect to landing area. m Estimate effects of load, wind, enemy, carrier speed and heading, visibility on execution of landing. n Control aircraft to maintain safe airspeed, altitude during approach to landing area.	

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
4.2 (Cont'd.)			o Identify landing area from instrument/navigation/visual information. p Identify position, speed and heading of aircraft with respect to landing site; select required position, speed and heading; control aircraft to achieve desired position, speed and heading. q Control airspeed, ground track and vertical speed to make safe touchdown; control ground path to achieve safe stop.	
4.3 Weapon Delivery and Gunnery	4.3.1 Identify target types. 4.3.2 Select gunnery weapon delivery modes to be employed. 4.3.3 Select flight path for weapon delivery. 4.3.4 Control aircraft and weapons to secure target effect. 4.3.5 Assess weapon effects.	a Target/weapon interactions. b Weapon system operating procedures. c Unit gunnery SOP's. d Gunnery safety procedures. e Crew communications procedures and SOP's.	a Target acquisition and recognition. b Coordinated control of flight path and weapon systems. c Safe handling of the aircraft during weapon delivery.	a Familiarization with target and target deployment characteristics. b Weapon system operating procedures and effects. c Gunnery and communications SOP's. d Practice in target acquisition and evaluation. e Practice in coordinated flight control, gunnery and communications.

TABLE 14. (cont'd) PERSONNEL TASKS REQUIRED TO OPERATE MILITARY SYSTEMS

SYSTEM FUNCTIONS	PERSONNEL FUNCTIONS	KNOWLEDGES	SKILLS	TRAINING SIGNIFICANCE
4.4 Individual Tactical Employment	4.4.1 Employ aircraft and systems in execution of tactical missions.	a Tactical SOP's and modes of aircraft employment. b Specific capabilities, limitations of aircraft and systems in specific tactical environments. c Effects of enemy units, deployments. d Relationships with other airborne, ground units. e Communications SOP's.	a Select routes to targets for element security and economy of operation. b Select attack, surveillance, reconnaissance modes. c Execute reconnaissance, attack missions to maximize effect and security. d Maintain communications within crew and between crew and related elements/units.	a Familiarization with tactics, enemy capabilities and deployments, unit and communication SOP's. b Practice in execution of essential mission elements in mission environment.
4.5 Tactical Application of Aircraft and Systems	4.5.1 Coordinate employment of aircraft and its systems within a tactical organization. 4.5.2 Employ aircraft and systems as element in complex tactical unit.	a Unit tactical SOP's. b Unit/individual mission responsibilities. c Unit/element tactical capabilities and limitations. d Unit communications SOP's.	a Employ aircraft as a weapon system in coordination with other similar/dissimilar systems. b Operate flight control, weapon communication and navigation systems while maintaining contact with friendly elements, while maintaining local security.	a Familiarization with capabilities, responsibilities of dissimilar friendly elements and units. b Familiarization with principles of employment of aircraft in combined units. c Practice in employment of aircraft and systems in combined units.

APPENDIX B

POTENTIAL TRAINING EXPERIMENTS

The data summarized in Tables 15 and 16 (Pages B-2 and B-26) were used as indications of the types of human factors problems encountered in the design of specific training devices. The studies cited in Table 15 illustrate the kinds of learning, training and device design experiments required in the past in dealing with the types of problems anticipated for the ETSS. In most cases, the studies cited reflect attempts to optimize learning within relatively specific contexts, indicating a continuing need for experimentation in the derivation, application and verification of device design concepts in specific training settings. The data summarized in Table 16 represent an application of the concepts in Table 15 to a specific, complex device design, indicating the manner in which a system like the ETSS would be used to define more precisely the characteristics of this type of device for more effective, efficient training application.

Table 16 is a matrix showing the extent of correspondence between the listing of training research problems in Table 15 and the characteristics of a relatively complex sample training device. The 2F88, the F4J Weapon System Trainer, was chosen as the example because of its complexity, and because it enables demonstration of the variety of decisions required in preparation of a training device specification, relative to the learning, perceptual, training and training control functions associated with the device.

Major experiment categories listed in Column 1 of Table 15 are represented across the top of Table 16, with entries in the table indicating the types of research problems associated with significant paragraphs of the specification. For example, paragraph V.B.7 of the specification calls for $+10^\circ$ and -4.5° of pitch motion in the trainer cockpit, $\pm 7.5^\circ$ in roll, 12 inches of heave and $\pm 7.5^\circ$ of motion in the yaw axis. While these motions may be appropriate for this device, other aircraft weapon system trainers and similar devices may require other motion capabilities in support of training in their own unique functions and modes of utilization. Similarly, other characteristics of this and other devices are subject to experimental analysis in the implementation of specific training requirements.

TABLE 15. ANTICIPATED ETSS EXPERIMENTS

LEGEND: T.A. - Training Aids
T.D. - Tactical Decision Making
SEN - Sensors
SYS - Systems

EXPERIMENT CATEGORY	RELATED ETSS MODULE*				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
1.0 **PERCEPTION OF THE TRAINEE STATION**					1.0 **PERCEPTION OF THE TRAINEE STATION**	
1.1 Determines requirements for operator station equipment.	2	4	2	4	Equipment Requirements Representation of the system operator's station in a training device facilitates training of operator responsibilities, but varies in completeness, with variations in the complexity of the tasks to be trained, the level to which training is to be accomplished in that device and with the approach to be employed in that segment of training. Displays, controls and ancillary equipment are incorporated at the trainee's station if they are required in or influence the performance to be trained. Equipment/training interactions are defined, in general, by the Training Situation Analysis. Specific interactions frequently require the collection of empirical training data, however, particularly when the operational and training systems under consideration differ significantly from the systems in which operator and training data are available.	Bate, A.J. and Self, H.C. Effects of Simulated Task Loading on Side-Looking Radar Target Recognition. AMRL TR-67-141, June 1968. AD 673 873.
1.1.1 Requirements for specific displays, controls and ancillary operator station equipment.						
1.1.2 Evaluate gradations in fidelity of representation of team elements and tactical units for effectiveness in training team members.						

* See Table 11, Page 141

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
1.1.3 Determines display and control fidelity requirements.					Display/Control Fidelity The extent to which equipment at the trainee station appears and performs like the corresponding equipment in the operator's station of the system for which training is to be provided has significance for the training value of the trainee station. Frequently, very high fidelity is essential for effective training, but as frequently, efficient control of learning requires low fidelity, as in the artificial enhancement of radar targets in facilitating early operator learning. Frequently also, the inability of the trainee to perceive and respond to basic elements of equipment fidelity make it unnecessary to incorporate them in the training device. While some fidelity requirements can be identified in the Training Situation Analysis, empirical analysis of the value of expenditures for trainee station equipment fidelity, and of the value of deliberate modifications of fidelity is required where past experience provides inadequate guidance.	HumRRO TR 65-4, June 1965. Functional and Appearance Fidelity of Procedures Trainer. Silver, C. A., Jones, J.M. and Landis, D. Analysis of Radar Training Requirements. NAVTRADEVCEN 1345-1, August 1966. Austin, W.R. Photographic Instrument Synthesizer. AFFDC TR-65-174, March 1966. Hearns, J.F. The Effect of Advanced Cueing on the Detection of Targets in a Visual Search Task. University Microfilms, #68-9176 (Ph. D. Dissertation). Elrod, W.H. et al. Human Factors Study for ASW Helicopter Tactical Team Trainer, Device 14H4. Vol. I, Honeywell Tech Doc. 267-65WC. June 1965. NAVTRADEVCEN 1568-2. Baker, R.A. Development and Evaluation of Systems for the Conduct of Tactical Training at the Tank Platoon Level. (HumRRO) April 1964. (AD 438 845)

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
1.2 Develop methods and techniques for providing feedback to the trainee. 1.2.1 Enhancement of normally-available feedback. 1.2.2 Development of audio, visual, tactile or other means of providing artificial feedback. 1.2.3 Development of feedback formats. 1.2.4 Develop means of displaying tactical data for trainee feedback, performance evaluation and trainee guidance.	1	3	1	4	Feedback Training effectiveness can be enhanced in many training situations by assuring that the trainee receives timely and relevant information concerning the effects of his performance, on the performance of the system or subsystem which he is learning to operate. Usually some information is available to the trainee as a consequence of the nature of the system. Sometimes this must be enhanced or processed to make it available at the proper time and/or in useful form. Sometimes artificial data must be generated to optimize learning rates, particularly in the early stages of learning in systems in which normal feedback is lacking, delayed or unclear. In many training situations, enhancement and generation of feedback must be curtailed to assure the development of trainee skills relevant to the operational system rather than to the system or device employed in training. In each of these cases, requirements for the design of and the value of feedback are sufficiently specific to the training subtasks to which they are related to necessitate empirical experimentation.	Hearns, J.F. The Effect of Advance Cueing on the Detection of Targets in a Visual Search Task. University Microfilms. #68-9176 (Ph.D. Dissertation). **Gordon, N.B. and Gottlieb, M.J. (Yeshiva University). Effect of Supplemental Visual Cues on Rotary Pursuit. J. Exp. Psychol., Vol. 75, December 1967, pp.566-568.** Buckout, R., Naylor, J.C. and Briggs, G.E. Effects of Modified Task Feedback During Training on Performance of a Simulated Attitude Control Task After Thirty Days. AMRL TDR-63-125, December 1963. Bowen, H.M., Bishop, E.W., Promisel, D. and Robins, J.E. Study, Assessment of Pilot Proficiency. NAVTRADEVCEN 1614-1, August 1966. Annett, J. (University of Aberdeen, Scotland). The Use of Cuing in Training Tasks: PHASE II.

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
1.3 Develop concepts and means of providing trainee control over the learning situation. 1.3.1 Development of self-instructional concepts for specific devices and device applications. 1.3.2 Development of methods for trainee identification, selection and practice of specific training problems.	1	3	1	4	Self-Instructional Concepts Instructional efficiency can sometimes be enhanced by permitting the trainee to participate in some limited aspects of training control. Under some circumstances, the trainee can diagnose his own level of performance, select exercises for practice and evaluate his own progress toward the criteria established for the specific training setting. The equipment used to facilitate this type of trainee participation reduces the fidelity with which the trainee's practice station represents the operational system operator's station. It must thus be designed for minimum interference with normal training, as well as for optimum utility.	

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE T.A.	T.D.	SEN	SYS	RATIONALE	PERTINENT LITERATURE
2.0 DETERMINATION OF REQUIREMENTS FOR THE REPRESENTATION OF DYNAMIC SYSTEM CHARACTERISTICS IN TRAINING DEVICES	1	3	1	4	2.0 PERCEPTION OF SYSTEM DYNAMICS In general, the training value of a training device relates directly to the degree to which it duplicates or represents certain characteristics of the system which it is intended to support. Training device cost is also related directly to degree of device fidelity, but overall training cost also includes the cost, and the danger of using operational equipment for training in lieu of high fidelity devices. Not all training requires high fidelity, but in general, the degree of fidelity required must be defined through the collection and analysis of data pertinent to the tasks, subtask and task elements being trained, using varying levels of device fidelity. Fidelity requirements also vary with the level of training under consideration. For example, fidelity of representation of a tactical unit is unlikely to be relevant in teaching basic leadership procedures, but may be critical in training tactical maneuvering skills.	**Muckler, F.A., Obermayer, R.W. Hanlon, W.H. and Serio, F.P. Transfer of Training with Simulated Aircraft** Dynamics. II. Variations in Control Gain and Phugoid Characteristics. WADD TR-60-615(II), December 1961. Rathert, G.A., Jr., Creer, B.Y. and Douvillier, J.G., Jr. Use of Flight Simulators for Pilot-Control Problems. February 1959. NASA Memorandum 3-6-59A. Ellis, N.C., Lowes, A.L., Matheny, W.G., Norman, D.A. and Wilkerson, L.E. (Life Sciences). Pilot Performance, Transfer of Training and Degree of Simulation. II. Variations in Aerodynamic Coefficients. May 1967, NAVTRADEVCEN 1889-1. Ellis, N.C., Lowes, A.L., Matheny, W.G. and Norman, D.A. Pilot Performance Transfer of Training and Degree of Simulation. III. Performance of Non-Jet Experienced Pilots vs. Simulation Fidelity. August 1968. NAVTRADEVCEN 67-C-0034-1. Mudd, Samuel. Assessment of the Fidelity of Dynamic Flight Simulators. Human Factors, Vol. 10, August 1968, pp.351-358.
2.1 Effects on training in power control with various levels and modes of display fidelity.						
2.2 Evaluation of the effectiveness for training aircraft VFR and IFR flight maneuvers of varying the fidelity of representation of the flight control system.						
2.3 Evaluation of the effect on the training of planesmen and diving officers of variations in the fidelity of representation of submarine hydrodynamic equations.						
2.4 Evaluation of requirements for fidelity of representation of hydrodynamic and motion equations for training in submarine and surface ship maneuvering and docking.						
2.5 Effects on driver training of variation in land vehicle dynamics over various surfaces.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
2.6 Evaluation of the effectiveness of training tactical commanders using varying types and levels of information about element and unit capabilities, characteristics and performance.						Demaree, R.G., Norman, D.A. and Matheny, W.G. (Life Sciences). An Experimental Program for Relating Transfer of Training to Pilot Performance and Degree of Simulation. NAVTRADEVCEN 1388-1, June 1965. Wilkerson, L.E., Norman, D.A., Matheny, W.G., Demaree, R.G. and Lowes, A.L. Pilot Performance, Transfer of Training and Degree of Simulation: I. Variations in Program Cycle Time and Aerodynamic Equations. December 1965. NAVTRADEVCEN 1388-2. Kidd, Edwin A., Gifford, B. and Harpur, R.P., Jr. In-Flight Simulation -- Theory and Application. April 1961. Presented at AGARD Specialists' Meeting, 10-14 April 1961.
2.7 Evaluate relative effectiveness of training team members vs. team as a whole.						
2.8 Evaluate use of instructor as a team member.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
3.0 DEVELOPMENT OF CONCEPTS AND TECHNIQUES RELATIVE TO THE PERCEPTION AND UTILIZATION OF ENVIRONMENTAL CUES TO SYSTEM STATUS AND PERFORMANCE IN OPERATUR TRAINING,					3.0 ENVIRONMENTAL SIMULATION The effects of the operational environment on operator performance and the utilization of environmental cues in the learning and execution of operator tasks are of major significance in the design of many training systems. Many environmental cues can be incorporated in synthetic training devices with relatively little difficulty or expense, but many which have significance for operator learning and performance cannot be provided for reasons of cost, safety and/or engineering feasibility. Some of the essential cues can be synthesized, provided adequate data are available on the manner in which they and their essential elements are perceived within a given task context. Where essential cues cannot be effectively reproduced or represented, it is necessary to allocate the training function to which they relate, to the operational system, or to some modification of the operational system. Experimental data specific to tasks and to the task environment are required in training system design, which reflect trainee perception of significant environmental cues, the influence of the cue on training, the level to which specific tasks can be trained in the absence of some cues, and the manner in which the operational system must be modified to make it a safe, economical and effective source of training in tasks	Valverde, H.H. Flight Simulators, A Review of the Research and Development. AMRL TR-68-97, July 1968. Aronson, M., Chea, F. Assault Boat Coxswain Trainer Feasibility Study. NAVTRADEVCEN 1H-58, February 1967. Stapleford, R.L., Peters, R.A., Alex, F.R. Experiments and a Model for Pilot Dynamics with Visual and Motion Inputs. NASA CR-1325, May 1969. Padgett, G.V., Dolph, R.J. (Lockheed). Oceanographic and Hydrographic Systems for Training. NAVTRADEVCEN 1494-1, May 1966. Kidd, Edwin A., Gifford, B. and Harpur, Robert P., Jr. In-Flight Simulation -- Theory and Application. Presented at the AGARD Specialists' Meeting on 10-14 April 1961. Warhurst, J.S., Cornell, J.A., Frizell R.V. (LSI). Underwater Environment Simulation Feasibility: Final Report NAVTRADEVCEN 1861-1, October 1966. USNTDC. Damage Control Training Position Paper. USNTDC T-3681, October 1967.

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
					requiring trainee exposure to cues not available in the synthetic portion of the training system.	
3.1 Evaluation of operator station motion as a source of cues to operator performance and training.	N/A	4	4	4	Trainee Station Motion Vehicle operators experience vehicle motion in the execution of their control tasks. These motions may act as distracting influences, and they may also provide cues to system status which are essential in timely and effective system control. Currently, adequate data are lacking on the sensitivity of system operators to motion, particularly in dynamic task environments, and in and along more than one body axis at a time. The ability of motion cues to summate with other sources of system data, and the influence of visual, sound and instrument cues on the perception of motion are also currently specified for most task situations. Basic research is required in this area, but more significant data are also needed in the design of specific training systems, to assure effective training in specific subtasks and task circumstances.	Bergerson, H.P. and Adams, James J. Measured Transfer Functions of Pilots During Two-Axis Tasks with Motion. NASA TN D-2177, March 1964. Sadoff, Melvin. A Study of a Pilot's Ability to Control During Simulated Stability Augmentation System Failures. NASA TN D-1552, November 1962. Gibino, D.J. (ASD). Effects of Presence or Absence of Cockpit Motion in Instrument Flight Trainers and Flight Simulators. ASD TR-68-24, June 1968. (AD 675 543) Kuehnel, Helmut A. Human Pilots' Dynamic Response Characteristics Measured in Flight and on a Non-Moving Simulator. NASA TN D-1229, March 1962. Stewart, J.D., Clark, B. (NASA-Ames). Comparison of Three Methods to Determine a Threshold for Perception of Angular Acceleration. A.J.P., Vol. 81, June 1968. Collins, W.E. (FAA). Adaption to Vestibular Disorientation. 8: "Coriolis" Vestibular Stimulation and the Influence of Different Visual Surrounds. AM 67-19, August 1967.
3.1.1 Determination of thresholds for motion along and around each of the three body axes.						
3.1.2 Determination of thresholds for motion along and around combinations of body axes.						
3.1.3 Evaluation of motion thresholds in complex task environments.						
3.1.4 Evaluation of the significance of operator station motion within a context of data from visual, sound and instrument sources.						
3.1.5 Identification of the degree and mode of utilization of motion cues in the execution of specific operator tasks.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
3.1.6 Analysis of differences in motion thresholds with differences in threshold indicators. (Reports vs. nystagmus vs. performance, etc.)						Buckout, R., Sherman, H., Goldsmith, C.T. and Vitale, P.A. The Effect of Variations in Motion Fidelity During Training on Simulated Low-Altitude Flight. ASD, AMRL TDR-63-108, Dec. 1963. Whiteside, T.C.D., Graybiel, A. and Niven, J.I. Visual Illusions of Movement. Flying Personnel Research Committee, London, England. June 1963. Brosgole, L. An Analysis of Induced Motion. NAVTRADEVCEN 1H-48, Feb. 1966.
3.2 Synthesis of valid representations of task relevant motions which cannot be duplicated in ground-based systems.	N/A	4	4	4		
3.2.1 Analysis of motion cue structure as it related to simple and complex sensory thresholds and motion-relevant behavior.						
3.2.2 Synthesis of alternate approaches to the production of perceptual equivalence for the simulation of essential motion cues.						
3.2.3 Evaluation of the subjective validity and the task-relevance of alternate approaches to motion cue synthesis.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
3.3 Development of methods of providing real-world visual cues essential in training specific skills. 3.3.1 Analysis of resolution, color, field of view, depth of field and visual motion required in training in specific tasks. 3.3.1.1 Rational analysis of task/cue relations. 3.3.1.2 Evaluation of task and training relevance of specific visual cue elements. 3.3.1.3 Evaluation of visual cue requirements in training contexts having various levels of task fidelity.	N/A	N/A	N/A	5	Visual Simulation Real-world visual information is essential in the performance of some critical system tasks. Some visual cues can be synthesized with little difficulty, but resolution, acutance, color, depth, motion and field of view requirements relative to certain classes of operator tasks are difficult if not impossible to provide in synthetic training systems. Few data are available, also, in defining visual cue requirements for specific tasks. Definitions of tasks and task elements are also frequently deficient in implying the significance of specific visual cues. In general, visual cues are essential in vehicle control, target detection, identification and acquisition, in gunnery, navigation, communication and tactical control. Engineering problems in the generation and display of visual cues vary with the nature of the task being trained, with the level of skill to be achieved and with the feasibility of supplementing training in the synthetic portions of the system with training in the operational environment. Experimental data relating elements of the visual scene available to the system operator, to operator performance and training of specific tasks are essential in developing training system and device designs which assure positive transfer of training, and which make economical use of the available display technology. Data are also	Chase , Wendell D. Pilot Simulator Display System Evaluation. Effective Resolution and Pilot Performance in the Landing Approach. NASA University Conference on Manual Control, 1967 (N68-15904). Palmer, E.A. (Ames) Experiments on Aim Point Estimation at Various Rates of Closure. (4th Annual Conference on Manual Control Systems, Ann Arbor, Michigan, 21-23 March 1968. NASA TM-X-61077 (NASA N68-23317). Bartley, S.H., Winters, R.W. Target Structure and Visual Distance. Journ. Psychol., Vol. 70, November 1968, pp.267-278. Pfeiffer, M.G., Clark, W.C. and Danaher, J.W. The Pilot's Visual Task: A Study of Visual Display Requirements. March 1963, NAVTRADEVCEN 783-1 (N63-16715). Aronson, M. Wide Angle Visual Simulatior Requirements and Experience. In, AIAA Simulation for Aerospace Flight Conf., August 26-28, 1963, Columbus, Ohio. Young, P.E., Hasbrook, A.H., Daniels, N.S., Dalbow, T.L. and Melton, R.J. Peripheral Vision Cues: Their Effect on Pilot Performance During Instrument Landing Approaches and Recoveries from Unusual Attitudes. FAA, AM 68-12, May 1968.

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
3.3.2 Evaluation of specific visual cue generation methods for providing effective task training.					required, specific to tasks, devices and training criteria, on the applicability of the various modes of visual cue presentation. Some modes appear appropriate to the presentation of cues required in learning specific tasks, but incompatible with others. Film systems, for example, seem appropriate in training basic gunnery skills, but incapable of providing effective training in the recognition of camouflaged targets.	Whitmore, P.G., Cox, J.A., and Friel, D.J. (HumRRO). A Classroom Method of Training Aircraft Recognition. TR 69-1, AD 666 093.
3.3.2.1 Rational analysis of display mode capabilities for providing specific task cue requirements.						
3.3.2.2 Evaluation of the training effectiveness of specific cues as provided by specific display modes.						
3.3.2.3 Evaluation of interactions among cue/task combinations for compatibility.						
3.4 Development of methods of providing aural cues essential in the training of specific operator tasks.	N/A	N/A	N/A	4	Aural Cue Simulation The sounds to which system operators are exposed can be important in masking essential information in distracting the operator from his primary tasks, and in facilitating his performance by providing essential cues to the performance, status and condition of the system and to the quality of his own performance. In sonar systems, of course, and in communications, sounds can be the primary focus of training. Many valid *a priori* judgments can be	Scott, D.A. (Ph.D. Thesis). The Influence of Unisensory and Bisensory Practice upon Auditory Discrimination. Univ. Microfilms #68-2359. Mackie, R.R., Harabedian, A. A Study of Simulation Requirements for Sonar Operator Trainers. (HFR). NAVTRADEVCEN 1320-1, March 1964. Vallerie, E.L. and Link, James M. (Dunlap). Visual Detection Probability of "Sonar" Targets as a Function of Retinal Position and Brightness
3.4.1 Spectral analysis of task-relevant sounds.						
3.4.1.1 Physical analysis of sound components.						
3.4.1.2 Subjective analysis of operator response to spectral components.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEM	SYS		
3.4.1.3 Correlation of sound spectral components with learning of operator task elements.					made as to requirements for the presence and the quality of sounds in operator training from the evaluation of Training Situation Analysis data. The significance of many specific sounds and sound components for learning require, however, experimental analysis of the training significance both of sound elements and of methods of presenting them to the trainee, within specific task and training contexts. Requirements for sound fidelity must also be established for specific tasks, training levels and trainee qualifications. Frequently, the presence or absence of a sound will fulfill the training requirement. In other instances, the quality of the sound will be significant in permitting the development of essential perceptual skills. In still other instances, it will be necessary to progressively manipulate the incidence, volume and the quality of task-significant sounds to facilitate the development of skill in recognizing and analyzing information which is crucial to the system operator's tasks.	Contrast. Human Factors, Vol. 10, August 1968. pp.403-411.
3.4.2 Development of preprogrammed and adaptive training sessions for training operators in sound analysis and classification.						
3.4.3 Identification of the significance of aural cues for the training of specific operator tasks.						
3.5 Identification and evaluation of the training effectiveness of alternate methods of simulating smoke, fire, heat, flooding, atmospheric pressure, odors and other sensory cues to task-relevant system and environmental conditions.	N/A	N/A	N/A	4		TDC. Study of Submarine Damage Control Training. NAVTRADEVCEN 1813-7, July 1966.

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TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
4.0 DEVELOPMENT OF CONCEPTS AND TECHNIQUES FOR AUTOMATIC PROGRAMMING OF INSTRUCTION					4.0 AUTOMATED INSTRUCTION Optimum training system design requires maximum objectivity in the administration, organization, monitoring, evaluation and guidance of the learning process. It also requires maximum utilization of the unique capabilities of instructional personnel in the evaluation, diagnosis and guidance of trainee performance. Automated instruction can maximize the objectivity of training and it can make optimum use of instructional personnel, through the systematic correlation of operator performance requirements, trainee capabilities and learning modes and instructor and computer capabilities. It can be effective in minimizing requirements on personnel which are not consistent with their unique capabilities.	Gebhard, R., Gradijan, J.M. and Brooks, F.A. Handbook for the Consideration of Training Functions During Design of Operational Equipment. NAVTRADEVCEN 1450-2, July 1965. Hickey, A.E. Computer-Assisted Instruction: A Survey of the Literature. Annual Tech. Rep. Oct 1966-July 1968, Entelek, Inc., Newburyport, Mass. TR-8. (AD 681 079). Torr, D.V., Morello, S. and Prevel, J.J. (General Learning Corp., Wash., D.C.) A Plan for the Establishment of a Computer-Aided Instruction Research and Development Center. July 1967. Casner, L.E. Study of Computers to Improve Command Post Exercises. NAVTRADEVCEN 1439-2, November 1965. Jeantheau, G.G., Anderson, B.G. (Dunlap). Training System Use and Effectiveness Evaluation. July 1966, NAVTRADEVCEN 1743-1. Angell, D., Shearer, J.W., Berliner, D.C. (AIR) Study of Training Performance Evaluation Techniques. NAVTRADEVCEN 1449-1, October 1964. Lersten, K.C. (USC, L.A.) Transfer of Movement Components in a Motor Learning Task. Research Quarterly, Vol. 39, October 1968. (NASA A69-80707).

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
						Chenzoff, A.P. and Folley, J.D., Jr. Guidelines for Training Situation Analysis (TSA). NAVTRADEVCEN 1218-4, July 1965.
4.1 Development of methods for the measurement of performance and learning.	1	3	1	4	Measurement of Learning A major prerequisite in the automation of training is the identification of performance parameters which relate to learning, and the establishment of performance criteria which reflect significant learning levels. Significant operator performance parameters can be identified in the Training Situation Analysis, but specific performance criteria frequently need to be derived from early experience with the operational system or with the prototype training system. Expensive modifications to prototype devices, and inefficient device utilization can be minimized by collecting experimental data on the use of specific performance parameters and criteria in training situation control prior to final device design.	Andressi, J.L. and Whalen, P.M. Physiological Correlates of Learning and Overlearning. June 1966, NAVTRADEVCEN 1H-56. Caro, Paul W. and Isley, Robert N. (HumRRO) Helicopter Trainee Performance Following Synthetic Flight Training. Professional Paper 7-66, November 1966. Bowen, H.M., Bishop, E.W., Promisel, D. and Robins, J.E. Study, Assessment of Pilot Proficiency. NAVTRADEVCEN 1614-1, August 1966. Smith, B.J. (Appl. Sci. As.) Task Analysis Methods Compared for Application to Training Equipment Development. NAVTRADEVCEN 1218-5, Sept. 1965. Perry, D.H. A Piloted Flight Simulator Study of Speed Instability During the Landing Approach. Royal Aircraft Establishment, Farnborough, England. Rept. No. TR-66138, April 1966. Smith, B.J. (Appl. Sci. As.) Task Analysis Methods Compared for Application to Training Equipment Development. NAVTRADEVCEN 1218-5, Sept. 1965.
4.1.1 Definition of criteria of learning and skilled performance in specific skills at specific stages of operator training.						
4.1.2 Validation of measures of performance and learning.						
4.1.3 Correlation of performance measures between low- and high-fidelity training devices.						
4.1.4 Development of formats for the display of performance measures for instructor use.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D	SEN	SYS		
						Federman, P. et al. Communications as a Measurable Index of Team Behavior. NAVTRADEVCEN 1537-1, October 1965. Knoop, P.A. Development and Evaluation of a Digital Computer Program for Automatic Human Performance Monitoring in Flight Simulator Training. AMRL TR-67-97, August 1967. Smith, Robert G., Jr. (HumRRO) An Annotated Bibliography on Proficiency Measurement for Training Quality Control. June 1964.
4.2 Development of Concepts and methods for facilitating instructor monitoring of trainee learning. 4.2.1 Correlation of performance measures and combinations of measures with the criteria of skilled performance. 4.2.2 Evaluation of direct and televised viewing of the trainee and the trainee station as a method of monitoring, evaluation and guidance. 4.2.3 Development of methods for the employment of the instructor as a member of a team of trainees.	1	2	1	4	Trainee Monitoring A basic function of the instructor in any training situation is the observation, evaluation and guidance of trainee performance. The instructor must be aware of the trainee's initial capabilities, his individual approach to the training process and his level of ability at a given time. He must also be aware of the criteria established for the specific training session under consideration, and he must be able to derive guidance techniques which will facilitate trainee achievement of these criteria. The instructor may acquire the information required to perform these functions in a number of ways, from informal contact with the trainee before and during training, to the use of test scores, performance displays	Anderson, A.E., Jr. and Streeter, E. (AIR) Functional Requirements for Aircraft Weapon System Trainer Instructor Station Display and Recording Systems. April 1965. NAVTRADEVCEN 1086-2. Smode, A.F. et al. The Measurement of Advanced Flight Vehicle Proficiency in Synthetic Ground Environments. MRL TDR-62-2, February 1962. Bowers, R. Utilization Study of Maneuvering Tactics Trainer, Device 1-BZ-2 SPECDEVCEN 20-A-10, September 1952. Z

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TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
4.2.4 Derivation of trainee performance data to support possible instructor evaluation and guidance actions.					and performance summaries derived automatically in the training session. The optimum method of acquiring and organizing performance data during training varies with the complexity of the task being trained, the number of parameters available for instructor evaluation, the nature of their intercorrelations, the qualifications of the instructor and the likely availability of instructor time. If qualified personnel are available, direct trainee observation is frequently effective, but when direct observation of trainee performance is difficult or where instructors have minimal qualifications, means must be developed for providing essential data in forms which require minimum interpretation. It may also be necessary to develop methods of automatically deriving and indicating evaluation and guidance approaches to further reduce instructor responsibilities. The specificity of appropriate methods of presenting performance data for instructor monitoring, and of the methods of facilitating instructor interpretation and utilization of performance data, with respect to the task, the trainee, the instructor and the training context, make experimentation essential in the development of effective means of implementing the monitoring function.	

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE T.A.	T.D.	SEN	SYS	RATIONALE	PERTINENT LITERATURE
4.3 Development of methods and techniques for the efficient control of training.	1	2	1	4	Training Control Training control is the means whereby trainees are oriented to training situations, introduced to specific training problems, exposed to various appropriate conditions of practice, evaluated, guided and finally rated for further training or for operational assignment. The efficiency and effectiveness of training relates directly to the quality of control exercises over the training process. Traditionally, the instructor has performed the actions which control the training situation, but current training methodology has tended to assign more and more of the routine aspects of training control to some preprogrammed automatic or semi-automatic means, leaving to the instructor those functions which require complex evaluation, judgments and instructional flexibility. Proper allocations of functions among training personnel and training equipment can greatly enhance training efficiency, but many functions can be allocated only after experimental analysis of the ability of equipment and personnel components of the training system to perform essential control functions, including pre-training briefing, variation of the conditions of practice, guidance and evaluation.	Zavala, A. and Geist, A.M. (AIR) Component Total Task Relationships: Simple and Sequential Practice Effects. August 1968, Human Factors, Vol. 10, pp.333-343. Sidorsky, R.C. et al. Research on Generalized Skills Related to Tactical Decision Making. NAVTRADEVCEN 1329-2, December 1956. Krumm, R.L. et al. Effectiveness of Integrated Flight Simulator Training in Promoting B-52 Crew Coordination. MRL TDR-62-1, February 1962.
4.3.1 Development of preprogrammed training packages.						
4.3.2 Development of methods of instructor monitoring of preprogrammed training sessions.						
4.3.3 Evaluation of possible methods of modifying preprogrammed training sessions during training.						
4.3.4 Development of methods for generating and programming automated training programs.						
4.3.5 Determination of optimum degrees and modes of instructor participation in the control of training situations.						
4.3.5.1 Allocation of evaluation and guidance responsibilities to the instructor and the training system computer.						
4.3.5.2 Development of methods of instructor-modification of the training situation, including task complexity, criterion levels, environmental conditions,						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.E.	SEN	SYS		
stresses, coaching and malfunction selection, insertion and deletion.						
4.3.5.3 Development of manual, automatic and semi-automatic briefing and debriefing schemes.						
4.4 Development of optimum means of utilizing computers in promoting efficient learning.	1	2	1	4	Computer-Aided Instruction Training system computers can perform some of the functions ordinarily required of instructor and operator personnel, when training functions have been carefully defined within a relatively specific training context. This tends to make training more objective and systematic, it tends to require more careful attention to the derivation of training objectives criteria and methods and it tends also to free instructors to perform the duties of which they are uniquely capable, in monitoring, evaluating and guiding the training process. Because of the relative inflexibility of computer programs, unusually careful and detailed planning is required in allocating specific functions to the system computer. Where knowledge of the system for which training is to be provided is limited, experiments are necessary to define meaningful subtasks, performance criteria, instructor data requirements for monitoring, effective conditions of practice, and potential guidance formats. Where the	Casner, L.E., Wieder, M.A., Littrell, R.M. and Thompson, R.M. Study of Computers to Improve Command Post Exercises. NAVTRADEVCEN 1439-2, November 1965. Englebart, D.C. and Sorensen, P.H. Explorations in the Automation of Sensorimotor Skill Training. NAVTRADEVCEN 1517-1, May 1965. Stolerow, L.M. Some Factors in the Design of Systems for Computer-Aided Instruction. (Harvard Computing Center). May 1968, TR-7 (AD 678740). (NASA N69-16257)
4.4.1 Evaluation of formats for the presentation of automatic feedback and guidance programs for training specific tasks to specific levels.						
4.4.2 Development of methods of scheduling automatic feedback and guidance programs in specific training devices and systems.						
4.4.2.1 Evaluation of potential performance criteria for the initiation of feedback and guidance programs.						
4.4.2.2 Evaluation of various performance criteria as feedback and guidance program initiators at various levels of training.						

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TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
4.4.2.3 Evaluation of the effect of specific feedback and guidance programs at various levels of training.					computer is to be used in adaptive control of training, experimental data are required concerning the basic dynamics of the task being trained, and of the process by which learning occurs. Data are also necessary concerning the ability of selection test data and data on trainee performance in the learning of similar and related tasks to predict learning rates and modes.	
4.4.3 Evaluation of alternate formats for the presentation of automated trainee briefings and demonstrations.						
4.4.4 Development of programs for automatic scoring of trainee performance.						
4.4.4.1 Evaluation of specific measures and scoring criteria as predictors of learning performance.						
4.4.4.2 Allocation of scoring criteria to specific levels of training.						
4.4.4.3 Evaluation of alternate methods of displaying performance scores for trainee and training program evaluation and improvement.						
4.4.5 Development of automated programs for the diagnosis of learning problems in specific training contexts.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
4.4.5.1 Correlation of combinations of aptitude scores and past and current performance scores and measures with criteria of skilled operator performance.						
4.4.5.2 Development of diagnostic and remedial programs for the improvement of trainee performance for specific training situations.						
4.4.6 Development of automated adaptive programs for the training of specific knowledges and skills.						Tallmadge, G.K., Shearer, J.W. Study of Training Equipment and Individual Differences. NAVTRADEVCEN 66-C-0043-1, March 1967. Mirabella, A. and Lamb, J.C. (GDEB) Computer Based Adaptive Training Applied to Symbolic Displays. NAVTRADEVCEN 1594-1, March 1966.
4.4.6.1 Analysis of task elements relevant to the identification of parameters for adaptive training through measurement and analysis of the performance of skilled and novice operator performance.						
4.4.6.2 Identification of critical task elements through correlation of learning performance in specific elements with the development of operator skill.						

TABLE 15. (cont'd) ANTICIPATED EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
4.4.6.3 Correlation of individual skill elements with trainee aptitude measures.						
4.4.6.4 Development of adaptive programs for training discrete, critical skill elements.						
4.4.6.5 Development of branching criteria for specific training situations.						
4.4.6.6 Development of adaptive programs for training specific skill elements to specific levels.						
4.4.6.7 Development of adaptive training sessions and programs through the combination of discrete training situations and branching programs.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
5.0 DEVELOP INSTRUCTOR-OPERATOR STATION DESIGNS TO ENHANCE DEVICE TRAINING EFFECTIVENESS					5.0 INSTRUCTOR/OPERATOR STATION DESIGN The instructor/operator station is the interface between the trainee and the instructor, the trainee and the training system and between the instructor and the training program. As such, it influences strongly the efficiency and the quality of the training. It permits the instructor to select, modify and initiate elements of training, and it permits him to monitor, evaluate, diagnose, guide and prescribe trainee behavior. The facility with which these functions are accomplished is a function of both the organization of the instructor's station and of the quality of the means it provides for displaying relevant information and for controlling meaningful training situation parameters. These, in turn, depend both on the quality and validity of a number of basic training and learning principles applied in the design of the instructor's station and on the relevance of the design of the specific instructor's station for the task, personnel and training problems under consideration.	Anderson, H.E., Jr. and Streeter, E. (AIR) Functional Requirements for Aircraft Weapon System Trainer Instructor Station Display and Recording Systems. April 1965, NAVTRADEVCEN 1086-2.
5.1 Develop instructor monitoring and control concepts applicable to specific training devices and situations. 5.1.1 Define teaching points, performance criteria for training situation.	1	3	4	4	Trainee Monitoring Every training task, at every level of training involves unique patterns of trainee activity which reflect, in some degree, the level of trainee ability at a given time. Analysis of these patterns as they relate to the criteria of effective system, subsystem and	AIR. Study, Aircraft Weapon System Trainer Instructor Station Display and Recording Systems. April 1965, NAVTRADEVCEN 1086-1. Sidorsky, R.C., Mara, T.D. Training Aspects of Computer-Aided Decision-Making. 1. Comparison of Two Approaches to Man-Computer Interaction. NAVTRADEVCEN 1329-3, July 1968.

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
5.1.2 Identify potential instructor monitoring, guidance and control requirements.					training performance, can provide information on the rate of learning, the learning mode being employed, the approach or approaches likely to improve the rate of learning and specific performance errors being made by the trainee. Sometimes sufficient useful information can be obtained by permitting the instructor to observe the trainee as he performs in a training session. Frequently, however, meaningful performance parameters can be made available to the instructor only through indirect indications of trainee behavior. While, in general, it is understood that the instructor requires unique information in evaluating trainee performance, the information required in relation to a specific training situation is highly specific to the task being trained, to the training situation itself, to the capabilities of the instructor, and to those elements of the task which are of primary significance at that particular level of training.	
5.1.3 Evaluate specific instructor participation modes for relative training value.						
5.2 Select optimum modes of display and control for instructor participation in training.	1	4	4	4	The selection of display and control modes and hardware can also be critical in facilitating instructor/operator station utilization. Many methods and components are available for displaying trainee, system and program data, and for controlling the training situation. Transilluminated indicators, CRT's, meters, knobs, joysticks, light pens and keyboards are some of the components having varying applicability to various training system functions.	Sidorsky, B.C., Mara, T.D. Training Aspects of Computer-Aided Decision-Making. 1. Comparison of Two Approaches to Man-Computer Interaction. NAVTRADEVCEN 1329-3, July 1968. Crook, M.N. et al. (Tufts) Trends and Developments in Visual Displays. December 1967. (AD 673 091) Gould, J.D. (IBM) Visual Factors in the Design of Computer-Controlled CRT Displays. Human Factors, Vol. 10, August 1968, pp.359-375. Busche Associates, California. Animated Panel Logic Programming Techniques. Final Eng Rept. June 1967-May 1968. NAVTRADEVCEN 67-C-0201-1, September 1968. (AD 677 476)
5.2.1 Define information and control requirements.						
5.2.2 Evaluate training effectiveness, effects on instructor efficiency of alternate modes of display and control.						

TABLE 15. (cont'd) ANTICIPATED ETSS EXPERIMENTS

EXPERIMENT CATEGORY	RELATED ETSS MODULE				RATIONALE	PERTINENT LITERATURE
	T.A.	T.D.	SEN	SYS		
					Selection of the most effective component requires that alternate components be evaluated within at least limited aspects of the training situation.	
5.3 Optimize instructor/student ratios for specific training situations.	1	4	4	4	Instructor/Student Ratios The use of automated and semi-automated training techniques tends to permit greater numbers of students to be trained by fewer instructors, even in those tasks which require individualized training. Economical training requires the use of as few instructors as possible, but it also requires that training quality and efficiency be maintained. As a result, the ratio of students to instructors must be optimized through evaluation of the specific modes and levels of participation required of the instructor in specific training settings, for economical, effective training to take place. This can be done through experimental analysis of instructor participation requirements in various discrete instructional tasks. It can also be analytically defined if sufficient data are available on the probable behavior of a population of trainees, and on the dynamics of learning behavior within a given task training context.	
5.3.1 Organize operator task data to represent trainee learning performance.						
5.3.2 Postulate trainee guidance requirements.						
5.3.3 Prepare trainee/instructor scenario incorporating trainee performance probabilities.						
5.3.4 Simulate training session, note instructor loads; allocate training tasks among instructor positions.						

TABLE 16. EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

	*1.0 TRAINEE STATION CONFIGURATION				2.0 DYNAMIC FIDELITY	3.0 ENVIRONMENTAL PERCEPTION & UTILIZATION				4.0 INSTRUCTIONAL MANAGEMENT AND PROGRAMMING						5.0 INSTRUCTOR STATION DESIGN	
DEVICE DESCRIPTION	DEFINE EQUIPMENT NEEDS	EVALUATE EQUIPMENT FIDELITY LEVELS	ESTABLISH SENSOR DISPLAY FIDELITY	EVALUATE FEEDBACK/ GUIDANCE DISPLAYS	EVALUATE LEVELS OF SYSTEM DYNAMIC FIDELITY	DEFINE MOTION CUE NEEDS	IDENTIFY VISUAL CUE REQUIREMENTS	EVALUATE VISUAL DISPLAY MODES	ESTABLISH AURAL CUE CHARACTERISTICS	EVALUATE PERFORMANCE MEASUREMENT METHODS	DEFINE TRAINEE MONITORING NEEDS	EVALUATE MONITORING DATA	EVALUATE MONITORING DATA DISPLAY MODES	EVALUATE COMPUTER AIDED INSTRUCTION MODES	EVALUATE ADAPTIVE TRAINING PARAMETERS/ METHODS	EVALUATE MODES OF INSTRUCTOR CONTROL	EVALUATE INSTRUCTOR/OPERATOR STATION COMPONENTS AND DESIGNS
	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
MILITARY CHARACTERISTICS FOR: Device No: 2F88 Device Name: F-4J Weapon System Trainer Date: 18 July 1968 M.C. No.: 2029A (U) II. TRAINING ENVIRONMENT A. These devices shall be used to train fleet pilots and RIOs under the direction of qualified instructors at Naval and Marine Corps Air Stations. B The devices will provide for the teaching of pilot skills, knowledge and procedures, including coordination between pilot and RIO for tactical maneuvers and weapons delivery. Individual RIO training in procedures and																	

* Refers to Experimental Category in Table 15

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
skills will also be a factor in training.																	
C. The devices will be used to provide realistic environmental, individual and team training.																	
...																	
V. TRAINING DEVICE DESCRIPTION NARRATIVE																	
B. Detailed Description																	
1. There shall be duplication(a) and activation(b) of the controls, instruments and other flight equipment at the pilot station and the radar intercept officer station so that the trainees may become completely familiar with the cockpit and controls and be able to synthesize flight and tactical maneuvers and to simulate emergencies. Activation of the controls and instrument response shall be accurate(c) through the entire operating range of the F-4J aircraft.	a	b c	c	b													
. . .																	
3. The components of the navigation system which are viewed, controlled or operated by trainees shall be identical in appearance and operation(d) to the actual equipment.			d														
. . .																	
b. Simulated wind. The following winds shall be provided while the aircraft is in flight.																	
(1) 0-300 knots in 10-knot increments(e).					e											e	
(2) 0-360 degrees in 10-degree increments(e).					e											e	
4. Flight Simulation																	
. . .																	

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TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
7. Cockpit motion(f) shall provide 10° up and 4.5° down in pitch, 7.5° left and right in roll, 12 inches up and down in heave, and 7.5° left and right in yaw. There shall be a system to provide buffet and to include any pitch moment encountered when entering or leaving the range of supersonic speeds.						f										f	
8. Aural simulation(g) shall be provided which will operate in either an earphone or speaker mode.									g								
9. Aircraft Systems - aircraft systems shall be simulated for normal, alternate, or emergency operation as per NAVAIR 01-245-FDD-1 and shall realistically affect the flight and system characteristics, the control responses and instrument and display indications for all conditions of operation. Simulation shall be complete except where noted(h).		h			h												
10. Emergency Operation (instrument and system failures)(i)		i			i											i	
11. Armament																	
a. Special Weapons Simulation - There shall be mounted within the pilot and RIO cockpits, those control units provided in the F-4J aircraft for weapon monitoring and delivery. The operation, function and sequence as described in NAVAIR 01-245-FDD-1 shall be completely simulated and correlated with the flight simulation(j).		j	j		j	j		j	j								
b. Missiles Simulation - All phases and configuration of arming, selection and launching of the missiles shall be completely simulated and correlated with the flight simulation(k). Missiles simulated will be the Sparrow III (AIM-7D), Sparrow III (AIM-7E), Sidewinder (AIM-9B), and Sidewinder (9D). Quantities, configuration and sequence of launching shall be as outlined in NAVAIR 01-245-FDD-1.		k	k		k	k	k	k	k								

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
c. Conventional Weapons - Conventional stores carried by the F-4J aircraft on the wing/centerline fuselage stations shall be simulated(l).		l	l		l	l	l	l	l								
. . .																	
e. Those parts of the bombing and fire control systems which are viewed, moved, controlled or operated by flight personnel shall be identical in appearance and operation(m) with the actual equipment.		m	m														
That portion which functions to operate the controls or indicators to display information to flight personnel, shall operate and portray similar information as the actual equipment(n).			n		n												
12. All-Weather Intercept - All modes of operation of the AN/AWG-10 MCS Fire Control System shall be simulated. The IFF presentation shall be simulated and controls shall be operable and displays shall be simulated(o). This portion of the overall F-4J Weapon System Trainer shall consist of the following major components.		o	o														
a. Target Simulation(p) - For the purposes of this military characteristic "target" shall be defined as any radar contact or electronic emitter (present or not present on the radar scope) which is computer generated and requires programming to provide present or future information other than radar landmass to the trainee.			p					p									
b. Target Control - Target control shall be such that the instructor will be able to exercise control of at least one hundred targets(q) by way of the following methods:		q	q				q	q								q	
(1) Pre-programmed problems(r) - a method by which the instructor develops tactical problems for insertion into the computer prior to the training period. Pre-programmed methods shall be capable of																r	

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
(a) reset to original parameters(s) without reinsertion of problem rate, cards, etc.																s	
(b) manual override and control of target parameters(t) and track information from the instructor console.																t	
NOTE: "Track" is defined for the purpose of this military characteristic as follows: a track shall contain not more than five legs of data information.																	
c. Radar Simulation - The device shall realistically simulate the performance characteristics of the AN/APG-59 Radar(u) as utilized with the AN/AWG-10 Missile Control System installed in the F-4J aircraft. The simulated radar shall respond to all radar set controls and shall affect all displays in a realistic manner(v). The normal effects of aircraft and target maneuvering shall be realistically simulated. All radar modes of operation and ranges shall be simulated. The radar simulation shall be correlated to the radar landmass system and to the missile simulation system(w), as applicable by radar mode selection. Those components of the AN/AWG-10 Missile Control System, such as the command indicator, which are located in the pilot's cockpit, shall be simulated(x) as outlined above, including the optical sight, and shall be furnished for installation into the flight portion of the device.		v x	u v w x				w	u w									
d. Antenna Simulator																	
(1) This unit shall realistically simulate antenna scanning motion and lobe patterns(y) of the APG-59 Radar Antenna to provide accurate target direction information to the radar simulator unit.			y					y									
e. Electronic Countermeasures (ECM) and Electronic Counter-Countermeasures (ECCM) Simulation - The ECM and ECCM simulation shall include realistic conditions existing in a hostile ECM environment(z)			z		z												

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
and shall permit realistic countermeasures to be taken(aa) as in the operational equipment.		aa															
(1) Equipment Systems - All automatic and manual modes of the operational ECM and ECCM equipments, including Built-In-Test (BIT) shall be functional(bb) in the simulated equipment and shall result in the proper performance characteristics(cc). Those portions of the ECM and ECCM equipments which are located in the pilot's cockpit shall be simulated as outlined above, and shall be furnished for installation into the flight portion of the device.		bb cc	bb cc		cc			cc									
(2) Panels, Displays and Controls - All panels, displays and controls shall be realistically simulated and located in the appropriate trainee compartment(dd) as in the operational F-4J aircraft.	dd	dd			dd												
(3) ECM Signal Simulation - ECM signal simulation shall provide for a minimum of two (2) relocatable surface-to-air missile (SAM) sites/complexes(ee). Each SAM site shall have the capability of generating a minimum of five (5) independent signal types. The simulated signals shall realistically affect all displays and indicators of the simulated equipments, as appropriate(ff). The sounds associated with the ECM signals shall be realistically simulated and presented in the pilot's and RIO's headsets(gg).		ee	ee ff gg		ee ff			ff	gg								
(4) ECM Signal Types - Signals shall be provided(hh) which will actuate, energize exercise or cause proper ECM warning and indications, both audio and visual, to appear in the trainee stations.		hh	hh		hh		hh	hh	hh								
(5) Countermeasure Action - ECM actions taken by the trainee, utilizing the simulated ECCM equipment shall automatically cause the proper indications to appear/disappear(ii) on the cockpit equipments without instructor action. The instructor		ii			ii												

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
shall have the capability of monitoring the trainee actions(jj).											jj	jj	jj			jj	
(6) Chaff Simulation - Realistic chaff simulation shall be furnished and shall include forward firing, angle firing, and bundle chaff. The chaff simulation shall affect all radar scopes in a realistic manner. It shall be possible to lock-on to the chaff and lose lock-on similar to actual operation from the aircraft(kk).	kk	kk	kk				kk	kk									
(7) Jamming - Simulated electronic jamming shall be furnished(ll) and shall include Barrage, Sweep, Range gate stealing, Velocity gate stealing and angle track deception.	ll	ll	ll				ll	ll									
The jamming shall affect all radar scopes in a realistic manner. It shall be possible to lock-on to the jamming and lose lock-on similar to actual AN/APG-59 operation.			ll		ll		ll	ll									
f. Radar Landmass Simulation - Realistic landmass video signals shall be generated by the RLMS(mm).			mm		mm		mm	mm									
These signals shall be supplied to the Radar Intercept Officer (RIO) radar indicator, the pilot radar indicator and the two instructor repeater indicators (tactics and flight), whenever conditions are such that these signals are received by the radar(nn) system.											nn	nn	nn				
Realistic simulation of radar returns shall be provided(oo) at aircraft altitudes from ground level to 50,000 feet, and shall include the situation when the simulated aircraft is flying at an altitude lower than the surrounding terrain.			oo		oo	oo	oo										
The design of the RLMS shall be such that the breakup of cultural targets shall be discernible within the operational capabilities of the AN/APG-59 radar. Ground clutter that would be normal for the terrain covered shall be simulated. The antenna patterns, including azimuth and vertical patterns, azimuth distortion and antenna scan rates, shall simulate the AN/APG-59 antenna system(pp).			pp		pp			pp	pp								
Full simulation of the RIO antenna control shall be provided(qq). The accuracy of the antenna simulation shall be congruent with the AN/APG-59 antenna system.		qq															

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TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
Elevation data shall be furnished to the flight portion for APN-141 Radar Altimeter simulation.																	
VI. INSTRUCTOR STATION																	
The instructor station is defined as the work area in which the instructor establishes the conditions of the problems, introduces emergency or system failures during the problem, and monitors the trainee's performance.																	
A. The instructor station shall reflect the equipment required for flight, tactics and integrated control, display and scoring(rr).										rr						rr	
B. The instructor station shall provide the capability of monitoring all aircraft instruments, indicators, and lights as portrayed at the pilot's and RIO enclosure(ss).											ss	ss	ss				
C. Provisions shall be made which will permit communication with a digital computer(tt) for:														tt		tt	
1. Problem selection.																	
2. Flight																	
(1) It shall be possible to preprogram performance bands for selected flight parameters(uu), to provide automatically recorded trainer performance deviation on selected maneuvers with identification of the specific performance deficiencies (that is, what parameter envelope was exceeded and at what point in the maneuver or mission). By means of the performance record, it will be possible to isolate the maneuver or operational circumstance in which the trainee's performance was deficient(vv).				vv						uu vv			vv	uu		uu vv	
(2) It shall be possible for the instructor to vary the allowable deviations defining the parameter envelope by pre-selection of calibrated values suited to the mission difficulty, trainee																	

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
proficiency, and relative significance of the parameter in the particular problem(ww).																ww	
b. Tactic - Envelopes as described for the flight portion shall be provided for the tactics portion(xx).										xx	xx	xx	xx	xx		xx	
2. ECM Locations - The instructor input panel shall provide for at least two SAM site complexes. Instructor shall have the capability of pre-programming these signals to appear automatically with override capability(yy).														yy		yy	
3. Environmental Controls - Environmental controls shall include but not be limited to the following:(zz)																zz	
a. Field elevation b. Magnetic variation c. Wind velocity d. Runway air temperature e. Aural simulation f. Barometric pressure																	
variation (NACA Standard) at sea level and runway temperature.																	
D. Communication Control - Communication controls and monitors shall include:																	
1. Inter-communication between the instructor(s), pilot, and RIO(aaa). A monitor shall be provided which will indicate what channel and mode (i.e., OFF, T/R or T/R + G) the trainee has selected. An indication of transmitting on ICS or radio shall also be provided.																aaa	
2. There shall be provided a voice tape recorder with VOX control to record the transmissions on the inter-communication system.																	
3. There shall be provided a private inter-communications system between instructors.																	

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
4. A maintenance inter-communication system shall be provided.																	
. . .																	
G. Aircraft Instrumentation - Repeaters, monitors, or readouts of the aircraft instruments, radar, navigation and bombing indicators shall be provided for instruction monitoring(bbb). These repeaters do not necessarily have to be actual aircraft equipment but shall reflect sound concepts of human engineering for instructional purposes.										bbb	bbb	bbb	bbb	bbb	bbb	bbb	
H. Flight Recorder and Tactics Display(ccc) - An appropriate display(s) shall be provided which will display:										ccc	ccc	ccc	ccc	ccc		ccc	
1. The current position and history of the track of own aircraft.																	
2. Targets (a/c, surface, geographical).																	
I. Coordinate Counters(ddd) - Displacement of the aircraft from the center of the flight recorder and/or the tactics display shall be shown in X-Y counters.										ddd	ddd	ddd	ddd	ddd		ddd	
J. Altitude Slew Control(eee) - The instructor shall be able to increase or decrease altitude at a rate of approximately 40,000 feet/minute by means of an altitude slew control.																eee	
K. Crash-Override Control(fff) - A crash-override switch shall be provided to override crash conditions.																fff	
L. Quantity Controls(ggg) - The instructor shall be able to vary the quantity of fuel and oxygen over the full range of the quantity gages.																ggg	
M. Store-Loading Controls(hhh) - Store loading controls will be provided to permit load, reload, change or remove external stores including weapons and drop tanks.																hhh	

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
N. Control Position Indicator(iii) - Indicators shall be provided to inform the instructor of the setting of cockpit controls where adequate indication of the control setting is not otherwise available and where such information is necessary.										iii	iii	iii	iii	iii	iii	iii	
O. Failure and Malfunction Controls(jjj) - Means shall be provided to enable the instructor to introduce malfunctions or failures to the trainee equipment. These malfunction switches shall be separated into two panels: 1. Flight 2. Tactics														jjj		jjj	
P. Programmed Malfunctions(kkk) - The instructor shall be able to program malfunctions to occur automatically at pre-selected points in the training mission.														kkk	kkk	kkk	
Q. Tactics Flight Generator(lll) - A flight generator shall be provided for independent modes of operation of the tactics portion.					lll											lll	
NOTE: The flight control shall be a gimbal-mounted manual control.																	
R. Scoring(mmm) - Scoring the trainee shall be as objective as possible. All indications, printouts, recordings shall provide a basis by which the instructor may compare past performance of other students, score and debrief the trainee. Scoring action may be made during the problem, at the conclusion of the problem, or by activation of the freeze control which will allow instruction or scoring at any intermediate point during the training period.										mmm				mmm			
. . .																	
4. Provisions shall be made for a Visual Presentation Attachment(nnn).							nnn	nnn									
. . .																	

TABLE 16. (cont'd) EXAMPLE OF ETSS UTILITY DURING 2F88 DESIGN PHASE

DEVICE DESCRIPTION	1.1	1.2	1.3	1.4	2.0	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2
IX. DEGREE OF COMPLEXITY AND ACCURACY REQUIRED																	
A. The complexity of this device will be kept at a minimum consistent with an accurate simulation of the flight, engine, and Weapons Systems Characteristics of the F-4J aircraft (ooo).		ooo		ooo													
B. Maximum implementation shall be made of human factors considerations in the design of the instructor station in order to insure optimal training value (PPP).										PPP	PPP	PPP	PPP	PPP	PPP	PPP	

APPENDIX C

TRAINING SIGNIFICANCE OF THE OPERATING ENVIRONMENT

The data in this appendix summarize the training significance of environmental cues to system status and operation, for each of the four systems considered in the study. They were used in defining both the need for experimental capabilities in supporting the design of specific devices, and in illustrating the extent to which these cue requirements are shared among the four systems (airborne, ocean surface, ocean subsurface, land).

TABLE 17. TRAINING SIGNIFICANCE OF THE OPERATING ENVIRONMENT

ENVIRONMENTAL CONDITION	TRAINING SIGNIFICANCE			
	SUBMARINES	SURFACE SHIPS	AIRCRAFT	LAND SYSTEMS
A. OPERATOR STATION MOTION: Motion of the Operator's Station due to system actions and/or environmental influences serves three functions: 1. Provides immediate cues to the operator on the direction and magnitude of control inputs required to correct system displacements due to operator or environmental inputs, or due to system and/or subsystem malfunctions. 2. Reinforces data presented through other means, facilitating operator interpretation of system status, reducing possibility of motion sickness with visual simulation. 3. Provides realistic distractions to operators in performance of normal and emergency functions, through: a. Requiring development of valid techniques for sharing attention among tasks and distractors. b. Degradation of operator performance capabilities, forcing development of techniques for compensating for degraded capabilities.	A. MOTION 1. Pitch: a. Alerts diving crews to plane angle requirements in achieving required diving angles and rates, and in maintaining desired depths. Alerts buoyancy control personnel to requirements for controlling distribution of ballast. b. Distracts attack teams, missile launch crews in performance of primary duties. 2. Roll: a. Alerts helmsman and diving party to changes in rudder, plane action in rapid turns. b. Acts as a minor distractor to all crew members in performance of their primary tasks.	A. MOTION 1. Pitch, roll, heave and yaw are of some significance in the handling of amphibious and assault craft in sea states and surf. They facilitate interpretation of boat handling dynamics and in planning landing maneuvers. 2. Lateral and longitudinal translations do not occur in sufficient magnitude to act as control cues. 3. Motions can act as task distractors for surface ship crews.	A. MOTION 1. Pitch: a. Alerts pilots to environmental, pilot inputs in pitch; defines magnitude and direction of correction required to maintain required flight path angle. Reinforced visual; instrument cues to flight path angle. Facilitates control of airspeed, rates of ascent and descent. b. Acts as distractor to other flight crew members; may alert bomb-nav operators to flight path disturbances of significance during bombing and weapon delivery runs. 2. Roll: a. Facilitates pilot control of attitude. Alerts pilots to uncoordinated turn conditions, and to onset of attitude changes. b. Acts as distractor to non-pilot crew members. 3. Yaw: a. Significant motion component in representation of multi-engine aircraft engine failures; provides immediate cue to direction and magnitude of heading input required to correct uneven thrust condition. b. Yaw is a minor component of	A. MOTION 1. Pitch: a. Significant cue to accelerator, brake control in tracked and wheeled vehicle operation. b. Significant cue to power skirt operation in ACV's. 2. Roll: a. Supports visual cues in vehicle operation. b. Provides cues to terrain effects in vehicle operation. c. May provide cues to heading control, skirt control in ACV's. 3. Yaw: Reduces incidence of motion sickness in vehicle operation. 4. Lateral Translation: a. Provides cues to terrain condition in

TABLE 17. (cont'd) TRAINING SIGNIFICANCE OF THE OPERATING ENVIRONMENT

ENVIRONMENTAL CONDITION	TRAINING SIGNIFICANCE			
	SUBMARINES	SURFACE SHIPS	AIRCRAFT	LAND SYSTEMS
	3. Yaw: a. Tends to reinforce visual cues to turning in close-in maneuvering and docking. b. Magnitude of yaw motion not likely to provide significant crew distraction. 4. Heave: a. Alerts crew to sea state both on and beneath the surface. b. Acts as minor task distractor in sea states. 5. Lateral/Longitudinal Translations: a. Unlikely to occur in such magnitude to act as control cue or distractor.		cues to heading change in large aircraft, when pilot position to vertical axis distance is great. More significant in short aircraft. 4. Lateral Translation: a. Major component of motions due to heading change in large aircraft. Provides immediate cue to outboard engine failures, unilateral spoiler, speedbrakes, flap failures. Particularly significant in takeoff. b. Provides cues to slipping and skidding in flight, and to runway condition in landing. c. Distractor to non-pilot crew members. 5. Longitudinal Translation: a. Provides significant cues to runway condition in taxiing and braking. b. Provides cues to engine, speedbrakes, afterburner, landing gear, spoiler and flap actions and malfunctions.	tracked/wheeled operation. b. Provides cues to heading requirements in ACV's, due to terrain slopes. 5. Longitudinal Translation: a. Provides minor cues to engine braking performance. 6. Heave: a. Minor cues to terrain condition. b. Provides cues to air cushion operation, malfunctions in ACV's.

TABLE 17. (cont'd) TRAINING SIGNIFICANCE OF THE OPERATING ENVIRONMENT

ENVIRONMENTAL CONDITIONS	TRAINING SIGNIFICANCE			
	SUBMARINES	SURFACE SHIPS	AIRCRAFT	LAND SYSTEMS
B. REAL-WORLD VISUAL SCENE: 1. Permits precise control of systems with reference to real-world objects and patterns. Permits development of realistic perceptual-motor skills through provision of real patterns of visual stimuli. 2. Permits development of realistic patterns of attention sharing among real-world and instrument cues to position, attitude and motion. 3. Provides realistic distraction to system operator in execution of his primary tasks.	B. VISUAL CUES 1. Provides information required in close-in maneuvering and docking, in estimating and controlling relative position, speed, bearing and heading of own and other vessel. 2. Provides information for weapon delivery on position, speed, bearing, course, magnitude and status of targets and potential targets.	B. VISUAL CUES 1. Provides information required in close-in maneuvering and docking, in estimating and controlling relative position, speed, bearing and heading of own and other vessel. 2. Provides information for weapon delivery on position, speed, bearing, course, magnitude and status of targets and potential targets.	B. VISUAL CUES 1. Provides data essential to some forms of air-to-air and air-to-ground weapon delivery. 2. Permits maneuvering with respect to other aircraft, and the terrain, in formation flight and low-level flight. 3. Permits adjustment of weapon fire and assessment of weapon effects. 4. Supports contact navigation.	B. VISUAL CUES 1. Permits vehicle operation over the terrain. 2. Permits target acquisition, weapon aiming, firing and assessment. 3. Permits contact with and control of ground and air elements. 4. Permits maneuvering with respect to targets, units, vehicles and obstacles.
C. AURAL CUES: Aural cues provide alerting, analytic and control data essential in the employment of military systems. 1. Provides alerting cues to system operators and unit personnel on environmental system and tactical events having direct and indirect significance for system, element and unit performance. 2. Provides cues to the nature of significant environmental events. 3. Permits control of systems, elements and units through reference to aural cues.	C. AURAL CUES 1. Provides essential information on system performance. 2. Indicates effects of weapons. 3. Provides data required to identify, classify and locate obstacles and potential targets. 4. Permits communications within the submarine and with other elements.	C. AURAL CUES 1. Provides essential information on system performance. 2. Indicates effects of weapons. 3. Provides data required to identify, classify and locate obstacles and potential targets. 4. Permits communications within the submarine and with other elements.	C. AURAL CUES 1. Provides essential information on aircraft system status and performance. 2. Permits crew communications and communication with other elements and units.	C. AURAL CUES 1. Provides cues required in vehicle control. 2. Permits evaluation of system status and performance. 3. Provides data on friendly, enemy actions. 4. Permits communications within and among elements and units.

APPENDIX D

EXTRACT FROM DEPARTMENT OF TRANSPORTATION AUTOMOBILE SIMULATOR SPECIFICATION

This appendix is an extract from a specification prepared by the United States Department of Transportation (Federal Highways Administration) for an advanced automobile simulator. This specification was used as an indicator of the problems likely to be encountered in simulating significant aspects of the automobile operator's environment. It was also used in Phase II, in deriving requirements for equipment and software essential to experimentation in ground vehicle training device design.

....The project shall include design requirements for a general-purpose automobile simulator which should permit rapid and efficient study of roadway configurations and in-vehicle displays related to the ERGS project.

The project shall provide hardware with the components and characteristics specified below. The contractor need not be limited to the following components, but may deviate where a better product will be produced by such deviation.

(1) Visual Display

An approximation of the real world necessitates that the subject/driver be able to focus his eyes at infinity. The use of an optical system which provides this capability through refractive collimation of an image is suggested. Display high-light brightness must exceed 10 ft. L. Field of view of about 30^{o}V x 60^{o}H is the minimum acceptable. Resolution of 2 min of arc display image would be desirable with 8 min of arc of resolution the limit acceptable.

Resolution of components of the visual system shall be specified for both optimal and typical operating conditions with component error analysis provided.

Image development shall be generated by a TV-Terrain model system. A Black and White TV system will be used, however, all possible components should permit change to color TV with minimum alteration.

Temperature deviation of $\pm 20^{o}$F from Normal environmental temperature of 70^{o}F must not degrade system operation.

Although model scale of 87:1 is desirable the overall size of the model should be as small as feasible. Gantry precision must permit location and control of probe within ±1 scale ft. of any desired point. The gantry, when translating in both X and Y coordinates, simultaneously should not deviate more than ±1 scale foot from the command path. Error analysis for each component in the control systems should be provided.

The subject driver must be able to drive on interstate highways, rural highways, and on urban streets. The interstate highway must have a diamond, a cloverleaf, and a cloverleaf with collector-distributor roadway interchanges each separated by one or more miles of highway. Nine additional non-standard interchanges should be capable of replacing any of the standard interchanges for a total of 12. Total replacement time for three interchanges should not exceed three hours. Interstate roadways must permit 100 mph at all points desirably with capability of 150 mph for short sections. The interchanges should be capable of variable spacing from closer than 1/2 mile to over two miles.

The rural roadway should be one or more miles of two-lane 50 mph specification highway and one or more miles of four-lane divided non-freeway. Urban streets with 25-30 mph design limits, frequent intersections and at least one traffic signal and one stop sign must be included. The following intersections must be provided: traffic circle, T, Y, and four-way right angle. The four-way must be represented in both two-lane and four-lane approach. Transitions should be provided to permit continuous operation over the entire simulated roadway segment. It is desirable that repetition from the beginning be easily accomplished with no discontinuity between scenes.

The visual system should permit the driver to move laterally over four lanes of traffic and yaw when appropriate for lane changes and other maneuvers.

Normal environmental traffic would be desirable. At intersections, for purposes of measurement, there should be no traffic for the last 30 seconds of approach. But on other sections traffic should be moving, and represent normal levels for a particular type of roadway. Speed deviations of ±10% between the subject's vehicle and other cars on the highway appear permissible.

(2) Motion System

Accurate motion of the vehicle cab correlated with the visual image of the roadway is required. Neither violent maneuvers nor highway/weather interactions are to be studied in the short-range research, so that simulation of high "g" forces will not be required.

Sustained lateral "g" forces to simulate turning are considered desirable.

(3) Vehicle Cab

The use of a contemporary, standard sedan configuration including the section from firewall to behind the front seat, and the full width of a normal car is required. The roof section and vehicle hood will also be included. Either a section of a vehicle or a new construction with similar appearance is required.

The interior will simulate an average American car. An automatic transmission selector and other typical instruments and controls will be included. Instruments and controls will operate. Instruments and controls will be modular and rapidly removable.

Strength of the unit must be such that the stresses from a future motion system will not cause component failure. The cab motion platform should be capable of being modified to support additional visual systems and permit alteration of center-of-gravity of the vehicle if required by future design considerations.

(4) Auditory System

Sounds correlated with engine/road speeds (produced electronically and under computer control) are required. An electromechanical system is not acceptable. A full roadway and vehicle sound simulation, i.e. pavement surface changes, air noise from opening vehicle windows, is desirable but is not required in the present simulator.............

APPENDIX E

EQUATIONS OF MOTION FOR AN AUTOMOBILE

During Phase II of the study, the equations representing the motions of a variety of vehicle systems were reviewed, relative to the selection of equipment and software for the ETSS. Although ground vehicles are generally considered less complex than air vehicles, it was noted that the simulation implications of ground vehicle motions are equally severe. The equations in this appendix illustrate the significance of these implications. They represent the mathematical model that is both necessary and adequate to predict the transient lateral response of an automotive vehicle to control inputs of steering wheel torque. The set of equations illustrates the complexity required for simulation of an automobile in a controlled environment--in the absence of terrain variations and aerodynamic forces.

The equations represent the lateral stability and control model for the free control automobile. That is, the stability characteristics which are associated with a steering wheel whose motion is unimpeded by the driver or the response produced by a torque applied to the steering wheel. For a detailed analysis of the subject the reader is directed to the reference. (41).

If the steering torque, M, is considered to be the input to the vehicle the following dimensional equations of motion as depicted in the following pages result for the free control automobile.

$$\begin{bmatrix} \left(I'_{sw}\frac{d^2}{dt^2} - M_{\delta sw}\right) & -M_{\delta fw} & 0 & 0 & -M_{\phi} \\ -H_{\delta' sw} & \left(I_{fw}\frac{d^2}{dt^2} - H_{\dot\delta}\frac{d}{dt} - H_{\delta' fw}\right) & -H_{\beta} & \left(I_{fw}\frac{d}{dt} - H_r\right) & \left(-H_p\frac{d}{dt} - H_{\phi}\right) \\ 0 & -Y_{\delta} & \left(MV\frac{d}{dt} - Y_{\beta}\right) & (MV - Y_r) & \left(M_s h\frac{d^2}{dt^2} - Y_{\phi}\right) \\ 0 & -N_{\delta} & -N_{\beta} & \left(I_{zz}\frac{d}{dt} - N_r\right) & \left(I_{xz}\frac{d^2}{dt^2} - N_{\phi}\right) \\ 0 & 0 & M_s hV\frac{d}{dt} & \left(I_{xz}\frac{d}{dt} + M_s hV\right) & \left(I_x\frac{d^2}{dt^2} - L_p\frac{d}{dt} - L_{\phi}\right) \end{bmatrix}$$

$$\times \begin{bmatrix} \delta'_{sw} \\ \delta_{fw} \\ \beta \\ r \\ \phi \end{bmatrix} = \begin{bmatrix} M' \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

where

$M_{\delta' sw} = -K_{ss}$

$M_{\delta ss} = K_{ss}$

$M_{\phi} = -\epsilon_1 K_{ss}$

$H_{\delta' sw} = K_{ss}$

$H_{\delta fw} = -K_{ss} - (AT_{\alpha_1} - C_1 x_t)$

$H_{\beta} = AT_{\alpha_1} - C_1 x_t$

$H_r = \frac{a}{V}(AT_{\alpha_1} - C_1 x_t)$

$H_{\phi} = \epsilon_1 K_{ss} + \lambda AT_{\gamma_1} - \lambda Y_{\gamma_1} x_t$

$H_p = I_{wp}\frac{V}{R_R}\lambda$

$Y_{\beta} = C_1 + C_2$

$Y_r = C_1\frac{a}{V} - C_2\frac{b}{V}$

$Y_{\delta} = -C_1$

$Y_{\phi} = -\epsilon_1 C_1 + \lambda Y_{\gamma_1}$

$N_{\beta} = aC_1 - bC_2 + AT_{\alpha_1}$

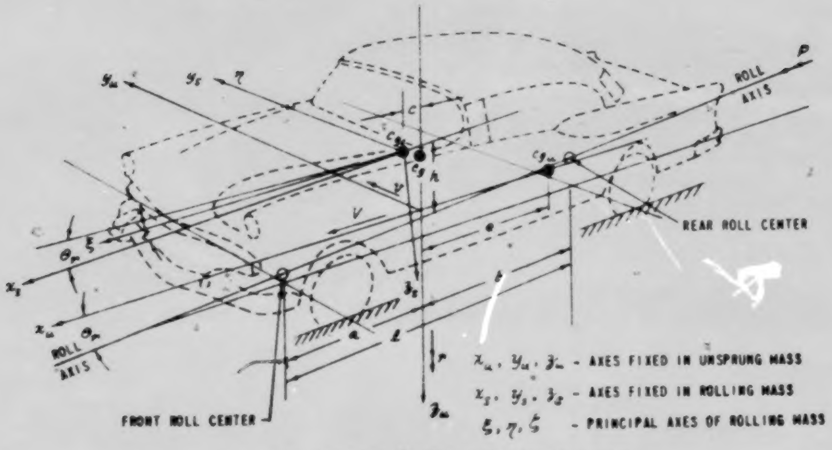
$N_r = \frac{a^2}{V}C_1 + \frac{b^2}{V}C_2 - \frac{b}{V}AT_{\alpha_1}$

$N_{\delta} = -aC_1$

$N_{\phi} = -\epsilon_1(AT_{\alpha_1} - bC_2) + a\lambda Y_{\gamma_1}$

$L_{\phi} = W_s h + k$

$L_p = \partial L/\partial p$


y_u
y_s
η
p
ROLL AXIS
c
c_{g_s}
c_g
h
c_{g_u}
v
V
e
θ_r
ζ
x_s
x_u
θ_r
ROLL AXIS
z_s
a
b
ℓ
r
z_u
REAR ROLL CENTER
FRONT ROLL CENTER
x_u, y_u, z_u - AXES FIXED IN UNSPRUNG MASS
x_s, y_s, z_s - AXES FIXED IN ROLLING MASS
ξ, η, ζ - PRINCIPAL AXES OF ROLLING MASS

Axis orientation in rolling and unsprung masses

It is convenient to nondimensionalize these equations by the same method used in [1]. The resulting equations are

$$\begin{bmatrix} (i'_{sw}D^2 - m_{\delta' sw}) & -m_{\delta rw} & 0 & 0 & -m_\phi \\ -h_{\delta' sw} & (i_{rw}D^2 - h_\delta D - h_{\delta rw}) & -h_\beta & (i_{rw}D - h_r) & (-h_p D - h_\phi) \\ 0 & -y_\delta & (\mu D - y_\beta) & (\mu - y_r) & (mD^2 - y_\phi) \\ 0 & -n_\delta & -n_\beta & (i_z D - n_r) & (i_{xz}D^2 - n_\phi) \\ 0 & 0 & m\mu D & (i_{xz}D + m\mu) & (i_x D^2 - l_p D - l_\phi) \end{bmatrix} \begin{bmatrix} \delta'_{sw} \\ \delta_{rw} \\ \beta \\ \hat{r} \\ \phi \end{bmatrix} = \begin{bmatrix} m' \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

where $\hat{r} = r\tau$, nondimensional yawing velocity, rad

$\tau = (l/g)^{1/2}$, sec

$\mu = \dfrac{V}{(lg)^{1/2}}$, vehicle Froude number

$D = \tau \dfrac{d}{dt}$, nondimensional derivative operator

$h_{\delta' sw} = H_{\delta' sw}/Mgl$

$h_\delta = H_\delta/Ml(gl)^{1/2}$

$h_{\delta rw} = H_{\delta rw}/Mgl$

$h_\beta = H_\beta/Mgl$

$h_r = H_r/Ml(gl)^{1/2}$

$i_{xz} = I_{xz}/Ml^2$

$i_x = I_{xx}/Ml^2$

$h_\phi = H_\phi/Mgl$

$h_p = H_p/Ml(gl)^{1/2}$

$i'_{sw} = I'_{sw}/Ml^2$

$i_{rw} = I_{rw}/Ml^2$

$i_z = I_{zz}/Ml^2$

$n_\delta = N_\delta/Mgl$

$n_\beta = N_\beta/Mgl$

$l_\phi = L_\phi/Mgl$

$l_p = L_p/Ml(gl)^{1/2}$

$m = Mh/Ml$

$m_{\delta' sw} = M_{\delta' sw}/Mgl$

$m_{\delta rw} = M_{\delta rw}/Mgl$

$m_\phi = M_\phi/Mgl$

$m'(t) = M'(t)/Mgl$

$n_r = N_r/Ml(gl)^{1/2}$

$n_\phi = N_\phi/Mgl$

$y_\delta = Y_\delta/Mg$

$y_\beta = Y_\beta/Mg$

$y_r = Y_r/M(lg)^{1/2}$

$y_\phi = Y_\phi/Mg$

Upon expanding the determinant of the characteristic matrix (nondimensional), there is obtained

$$\begin{aligned} \Delta = {} & D^8(i'_{sw}i_{rw})A + D^7(i'_{sw}i_{rw}B - h_\delta i'_{sw}A) + D^6[i'_{sw}i_{rw}C - h_\delta i'_{sw}B + A(-i'_{sw}h_{\delta rw} - m_{\delta' sw}i_{rw}) + y_\delta i'_{sw}A_1 - n_\delta i'_{sw}A_2] \\ & + D^5[i'_{sw}i_{rw}E - h_\delta i'_{sw}C + B(i'_{sw}h_{\delta rw} - m_{\delta' sw}i_{rw}) + m_{\delta' sw}h_\delta A + y_\delta i'_{sw}B_1 - n_\delta i'_{sw}B_2] \\ & + D^4[i'_{sw}i_{rw}F - h_\delta i'_{sw}E + C(-i'_{sw}h_{\delta rw} - m_{\delta' sw}i_{rw}) + m_{\delta' sw}h_\delta B + A(m_{\delta' sw}h_{\delta rw} - h_{\delta' sw}m_{\delta rw}) \\ & \quad + y_\delta i'_{sw}C_1 - m_{\delta' sw}y_\delta A_1 - n_\delta i'_{sw}C_2 + m_{\delta rw}n_\delta A_2] \\ & + D^3[-h_\delta i'_{sw}F + E(-i'_{sw}h_\delta - m_{\delta' sw}i_{rw}) + m_{\delta' sw}h_\delta C + (m_{\delta' sw}h_{\delta rw} - h_{\delta' sw}m_{\delta rw})B \\ & \quad + y_\delta i'_{sw}E_1 - m_{\delta' sw}y_\delta B_1 - n_\delta i'_{sw}E_2 + m_{\delta rw}n_\delta B_2] \\ & + D^2[F(-i'_{sw}h_{\delta rw} - m_{\delta' sw}i_{rw}) + m_{\delta' sw}h_\delta E + C(m_{\delta' sw}h_{\delta rw} - h_{\delta' sw}m_{\delta rw}) + y_\delta i'_{sw}F_1 \\ & \quad - m_{\delta' sw}y_\delta C_1 - n_\delta i'_{sw}F_2 + m_{\delta rw}n_\delta C_2 + h_{\delta' sw}m_\phi C_3] \\ & + D[m_{\delta' sw}h_\delta F + E(m_{\delta' sw}h_{\delta rw} - h_{\delta' sw}m_{\delta rw}) - m_{\delta' sw}y_\delta E_1 + m_{\delta rw}n_\delta E_2 + h_{\delta' sw}m_\phi E_3] \\ & + F(m_{\delta' sw}h_{\delta rw} - h_{\delta' sw}m_{\delta rw}) - m_{\delta' sw}y_\delta F_1 + m_{\delta rw}n_\delta F_2 + h_{\delta' sw}m_\phi F_3 \end{aligned}$$

where

$$\begin{aligned} A &= \mu(i_z i_x - i_z m^2 - i_{xz}^2) \\ B &= \mu(m^2 n_r - i_z l_p - n_r i_x - m i_{xz} y_r) - y_\beta i_z i_x - y_\beta i_{xz}^2 - i_{xz} m n_\beta \\ C &= \mu(n_r l_p + n_\beta i_x + m i_z y_\phi - i_z l_\phi - n_\beta m^2 + i_{xz} n_\phi + m i_{xz} y_\beta) + y_\beta i_z l_p + y_\beta n_r i_x - n_\beta y_r i_x \\ E &= \mu(n_r l_\phi - n_\beta l_p + m n_\phi y_r - m y_\phi n_r) + y_\beta l_\phi i_z - y_\beta n_r l_p + n_\beta y_r l_p + i_{xz} n_\beta y_\phi - i_{xz} y_\beta n_\phi \\ F &= \mu(m n_\beta y_\phi - m y_\beta n_\phi - n_\beta l_\phi) + n_\beta l_\phi y_r - n_\beta n_r l_\phi \end{aligned}$$

$$\begin{aligned} A_1 &= i_{rw} m i_z \mu \\ B_1 &= h_\beta i_{xz}^2 - h_\beta i_z i_x + n_\beta i_{rw} i_x - m\mu h_r i_{xz} + m\mu h_p i_z \\ C_1 &= i_z l_p h_\beta + i_x n_r h_\beta + i_{xz} m\mu h_\beta - n_\beta i_{rw} l_p - n_\beta h_r i_x - m\mu i_{rw} n_\phi + m\mu h_\phi i_z + h_p n_\beta i_{xz} - n_r m\mu \\ E_1 &= h_\beta i_z l_\phi - n_r l_p h_\beta - n_\phi i_{xz} h_\beta - n_\beta i_{rw} l_\phi + n_\beta h_r l_\phi + n_\beta h_\phi i_{xz} + m\mu h_r n_\phi - m\mu h_\phi n_r + h_p n_\beta m\mu \\ F_1 &= -h_\beta n_r l_\phi - h_\beta n_\phi m\mu + n_\beta h_r l_p + n_\beta h_\phi m\mu \\ A_2 &= m^2 i_{rw} \mu - \mu i_{rw} i_x \\ B_2 &= m i_{xz} h_\beta + \mu l_p i_{rw} + h_r i_z \mu + y_\beta i_{rw} i_x - \mu m^2 h_r - h_p i_{xz} \mu \\ C_2 &= h_\beta m^2 \mu - h_\beta i_x [\mu - y_r] + \mu l_\phi i_{rw} - \mu h_r l_p - \mu h_\phi i_{xz} - y_\beta l_p i_{rw} - y_\beta h_r i_x - m\mu i_{rw} y_\phi + h_p(y_\beta i_{xz} - m\mu y_r) \\ E_2 &= h_\beta l_p [\mu - y_r] - h_\beta i_{xz} y_\phi - \mu h_r l_\phi - y_\beta l_\phi i_{rw} + y_\beta h_r l_p + y_\beta h_\phi i_{xz} + m\mu h_r y_\phi - m\mu h_\phi y_r + h_p y_\beta m\mu \\ F_2 &= h_\beta l_\phi [\mu - y_r] - h_\beta m\mu y_\phi + y_\beta h_r l_\phi + y_\beta h_\phi m\mu \\ C_3 &= y_\delta i_z m\mu - n_\delta \mu i_{xz} \\ E_3 &= y_\delta n_\beta i_x - y_\delta m\mu n_r + m\mu y_r n_\delta - y_\beta i_{xz} n_\delta \\ F_3 &= y_\delta n_\beta m\mu - n_\delta y_\beta m\mu \end{aligned}$$

Nomenclature

AT = aligning torque produced by two front or rear tires, ft-lb

AT_α = $\partial AT/\partial\alpha$, combined aligning stiffness of right and left tires, ft-lb/rad

a = distance between vehicle cg and front wheel center, ft

b = distance between vehicle cg and rear wheel center, ft

c = distance measured horizontally from cg of M to cg of M_S, ft

C = $C_1 + C_2$, total cornering stiffness of vehicle, lb/rad

C_1 = $\partial Y/\partial\alpha_1$, cornering stiffness of both front tires, lb/rad

C_2 = $\partial Y/\partial\alpha_2$, cornering stiffness of both rear tires, lb/rad

GR = gear ratio of steering system, $(N_L \times N_G)$

g = acceleration of gravity, ft/sec²

h = height of the cg of rolling mass above the roll axis, ft

I_ξ, I_ζ = principal moments of inertia of M_S, slug-ft²

I_{zT} = moment of inertia of vehicle about vertical axis through its cg, slug-ft²

I_{xs} = $I_\xi \cos^2 \epsilon + I_\zeta \sin^2 \epsilon + M_s h^2$, slug-ft²

I_{xz} = $I_\zeta \cos(\theta_R - \epsilon) \sin \epsilon + I_\xi \sin(\theta_R - \epsilon) \cos \epsilon + M_s hc$, slug-ft²

I_{w_p} = polar moment of inertia of both front wheels about axle, slug-ft²

i = $\sqrt{-1}$

KT = kingpin torque, ft-lb

k = roll stiffness of suspension, ft-lb/rad

L = rolling moment about x-axis, ft-lb

l = wheelbase, ft

M = total mass of vehicle, slugs

M_s = rolling mass of vehicle, slugs

M_u = nonrolling (unsprung) mass of vehicle, slugs

N = yawing moment about vertical axis through cg of vehicle, ft-lb

p = angular velocity of rolling mass relative to unsprung mass, rad/sec

R_r = rolling radius of tire, ft

r = yawing velocity of unsprung mass, rad/sec

SWT = steering wheel torque, ft-lb

t = time, sec

t_1 = front-wheel tread

V = forward velocity of vehicle, fps

v = lateral velocity of unsprung mass along y-axis, fps

W_s = weight of rolling mass, lb

x_c = trail distance for positive caster angle, ft

Y = force along y-axis, lb

Y_γ = $\partial Y/\partial\gamma$, tire side force per unit camber angle, lb/rad

z = height of roll center above ground, ft

α = tire slip angle, rad

β = sideslip angle of vehicle, rad

γ = camber angle of front wheels, rad

δ_{FW} = front-wheel displacement, $(\delta_L + \delta_R)/2$, rad

L_p = roll damping produced by shock absorbers, ft-lb-sec/rad

ϵ_1 = $\partial\delta_{FW}/\partial\phi$, front roll steer, rad/rad

ϵ_2 = $\partial\delta_2/\partial\phi$, rear roll steer, rad/rad

λ = $\partial\gamma/\partial\phi$, rate of change of camber angle per unit roll angle of sprung mass, rad/rad

ϕ = roll displacement of rolling mass about roll axis, rad

θ_R = inclination of roll axis below horizontal, rad

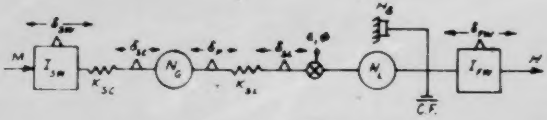
ϵ = inclination of principal axis of M_s above roll axis, rad

Subscripts

ss = steady state

1 = front wheels

2 = rear wheels



Schematic of steering system

where

M = driver applied steering torque, ft-lb

I_{SW} = steering-wheel inertia, slug-ft²

δ_{SW} = steering wheel displacement, rad

K_{SC} = steering-column flexibility, ft-lb/rad

δ_{SC} = steering-column displacement, rad

N_G = gear ratio of gearbox

δ_P = pitman shaft displacement, rad

K_{SL} = steering-linkage flexibility ft-lb/rad

δ_{SL} = steering-linkage displacement, rad

N_L = gear ratio of steering linkage

CF = Coulomb friction, ft-lb

I_{FW} = moment of inertia of both front wheels about kingpin, slug-ft²

δ_{FW} = front-wheel displacement, rad

H_δ = viscous damping derivative, ft-lb sec/rad

H = kingpin torque owing to tire forces and moments, ft-lb

η_F = forward efficiency of gearbox

APPENDIX F

AIRBORNE VEHICLES

1. This appendix considers the characteristics of all aircraft -- military and civilian -- dirigibles and certain aspects of air cushion vehicles as they appertain to the motion and visual requirements. These vehicles are characterized by the following modes of operation, each of which has its respective operational and training implications:

1. Ground handling operations
2. Takeoff and landing
3. Conventional flight
4. Abnormal flight

The range of flight profiles considered encompasses:

1. Taxiing
2. Takeoff and climb
3. Approach and landing
4. Airwork and aerobatics
5. Formation flying
6. Navigation and low-level flying
7. Night flying

1.1 THE MOTION CHARACTERISTICS OF AIRBORNE VEHICLES. Movement of an air vehicle on an apron, runway, or taxiway is felt by the operator as random, low-frequency, low-amplitude, multidirectional oscillations. These oscillations are dependent on the extent of irregularities in the surface of the pavement. The vehicle also experiences forces caused by brake applications, asymmetric thrust and exercise of direction control.

The ground roll portion of either a takeoff or landing is defined with respect to vehicle motion by the preceding paragraph. During a takeoff, the instant that a vehicle becomes airborne the ground roll rumble ceases. The vehicle usually assumes a nose-high attitude, and various longitudinal accelerations occur as thrust is changed, gear retracted and high-lift devices retracted. During the landing phase the procedure occurs in reverse order, with buffeting occurring as the various devices are extended, and as rotor downwash is reflected from the ground and/or fuselage. At touchdown, an impact of the vehicle with the pavement occurs and, dependent on whether or not the vertical momentum is greater than the absorption capabilities of the landing gear, a bounce may occur. Asymmetric touchdown causes longitudinal and lateral motion of the vehicle.

During conventional flight, which includes straight and level flight, turning flight, climbing and descending flight and all other modes of flight that are continuous in nature and not influenced by external forces, the vehicle is capable of moving in three translational and three rotational degrees of freedom. The extent of the motion in any of these degrees is indicated by the mode of flight and the type of vehicle. The effects of characteristic periodic oscillations, such as the phugoid, short-period oscillations, Dutch roll and lateral instability oscillations, are superimposed on the basic motions.

The abnormal region of flight comprises all circumstances not covered by the preceding three paragraphs, including those motions of the vehicle that are not controlled by the operating crew: stall, stall buffet, blade stall, Mach buffet, post-stall gyration, wing drop, spin, upset due to turbulence and effects due to malfunctions or vehicle equipment.

Determination of the parameters for an air vehicle motion base has always been a very subjective and much discussed item. Many reports have been written on the subject, but none have explicitly related vehicle performance to motion base characteristics. In view of the fact that little factual information is available for the characteristics of a motion base for an air vehicle, a summary of simulator requirements is shown in Table 18 (Page F-3). It is suggested that the characteristics chosen for the ETSS lean toward the maximum values, thus allowing for experimentation in determination of suitable characteristics for an air vehicle simulator with a motion platform.

1.2 The Visual Characteristics of Airborne Vehicles. A study (39) to determine the optimum visual system for a flight simulator capable of performing those flight profiles has been conducted by Link. The observations of this study are shown in Table 19 (Page F-4). Four visual systems were proposed to cover all aspects of the listed flight profiles.

Since the primary purpose of any simulator is to provide training in vehicle operation without using operational vehicles, it is reasonable to choose a research visual system

TABLE 18. SUMMARY OF AIRBORNE VEHICLE MOTION SYSTEM CHARACTERISTICS

VEHICLE TYPE

MOTION PARAMETER	707	DC8	747	727	NASA AMES	NASA MINIMUM	DC10	L1011	HS HARRIER	F15	J37	ATD	SPTS	F4J	F111	* UPT
EXCURSIONS:																
Pitch (Deg)	+14,-6	+15,-6	+30,-20	+15,-6	±22	±20	+27,-20	+30,-20	+28,-17	Similar to SPTS	±26	+14,-9	±15	+11,-5	+14,-6	As For 747
Roll (Deg)	±9	±10	±22	±10	±45	±10	±20	±22	±24		±18	±15	±15	±8	±13	
Yaw (Deg)	NA	NA	±32	NA	±30	NA	±40	±32	[illegible]		NA	NA	±15	NA	±3	
Vertical (in)	24	24	+39,-30	24	±60	±36	+28,-28	+39,-30	±30		±3	±24	±12	±12	±24	
Lateral (in)	NA	NA	±48	NA	±600	±36	±50	±48	±48		NA	±6	±15	±15	±6	
Longitudinal (in)	NA	NA	+49,-48	NA	±48	NA	+50,-60	+49,-48	NA		NA	NA	±6	NA	NA	
VELOCITIES:																
Pitch deg/sec	±9	±15	±15	±15	±40	①	±15	±15			±50	±15	±15	±15	NA	
Roll "	±14	±20	±15	±20	<±103		±15	±15	NA		±46	±17	±17	±17	NA	
Yaw "	NA	NA	±15	NA	±40		±10	±15			NA	NA	±15	NA	NA	
Vertical in/sec	±12	±12	±24	±12	±103		±24	±24			±32	11	±12	±12	NA	
Lateral "	NA	NA	±24	NA	±240		±24	±24	NA		NA	13	±15	±15	NA	
Longitudinal "	NA	NA	±24	NA	±75		±24	±24			NA	NA	±12		NA	
ACCELERATIONS:																
Pitch deg/sec^2	73	46	±25	46	±115		[illegible]	±25	±118		±600	±25	±25	±25	73	
Roll "	143	79	±50	79	±230		±20	[illegible]	±118		±900	±50	±70	±70	53	
Yaw "	NA	NA	±50	NA	±115		±10	±50	[illegible]		NA	NA	±100	NA	53	
Vertical in/sec^2	308	77	308	77	192		310	308	132		780	+308,-384	308	+308,-384	308	
Lateral "	NA	NA	230	NA	180		77	230	132		NA	±182	77	±182	231	
Longitudinal "	NA	NA	230	NA	120		77	230	NA		NA	NA	182	NA	NA	

① This set of numbers represents the minimum requirements for a motion platform (NASA) Lag < 0.2 Sec in angular response. Frequency response > 5 Hz and flat to 1½ Hz.

* Undergraduate Pilot Training

TABLE 19. VISUAL SYSTEM REQUIREMENTS FOR FLIGHT TRAINING

PARAMETER		TAXIING	TAKEOFF & CLIMB	APPROACH & LANDING	AIRWORK & AEROBATICS	FORMATION FLYING	NAVIGATION & LOW LEVEL	NIGHT FLYING
Field of View:	Up	15°	15°	60°	120°	90°	15°	60°
	Down	45°	30°	45°	45°	10°	45°	45°
	Left	60°	90°	120°	120°	90°	90°	120°
	Right	60°	90°	120°	120°	90°	90°	120°
Resolution (Arc Minutes)		5-10	5-10	3-6	10-15	3-6	5-15	3-6 ("point" lights)
Highlight Brightness (Foot-Lamberts)		B > 8	B > 8	B > 8	B > 8	B > 8	B > 8	B > 2 (lights)
Contrast: ($\frac{\Delta B}{B}$)	B&W	25:1	25:1	25:1	25:1	25:1	25:1	25:1
	Color	15:1	15:1	15:1	15:1	15:1	15:1	25:1
Image Content • Desired items not required for basic task		Taxiway Structures or obstacles • Parked aircraft and/or ground support equipment • Moving aircraft and/or ground support equipment	Runway Airport buildings and structures Horizon ref and sky •Other aircraft	Runway Airport buildings and structures Horizon ref. and sky Surrounding terrain detail • Other aircraft • Wingtips	Horizon reference and sky Wingtips • Isolated cloud forms • Ground detail Ground references points	Lead aircraft Horizon reference • Other aircraft in formation	Horizon reference Terrain contour and detail correlated with charts and maps Recognizable target or identification points	Horizon reference Runway lighting • Airport facilities lighting • City and other cultural lights • Stars
Performance Range	X:	≥ 2 miles of taxiway	≥ 10 miles	≥ 10 miles	Not required	Reference to lead aircraft: 0 - 2 miles	≥ 150 miles	≥ 10 miles
	Y:	≥ 50 feet	≥ 5 miles	≥ 5 miles	Not required	0 - 2 miles	≥ 150 miles	≥ 5 miles
	Z (Altitude):	±6 inches	5 ft. ≤ h ≤ 2500 ft.	5 ft. ≤ h ≤ 2500 ft.	6000' ≤ h ≤ 30,000'	0 - 2 miles	100 ≤ h ≤ 10,000 ft.	5 ft. ≤ h ≤ 2500 ft.
	Roll:	±10°	-60° ≤ φ ≤ +60°	-60° ≤ φ ≤ +60°	Continuous	±15°	-60° ≤ φ ≤ +60°	-60° ≤ φ ≤ +60°
	Pitch:	±8°	0° ≤ θ ≤ 30°	-30° ≤ θ ≤ +30°	Continuous	±15°	-60° ≤ θ ≤ +60°	-30° ≤ θ ≤ +30°
	Yaw:	± 15°	-90° ≤ ψ ≤ +90°	Continuous	Continuous	±15°	Continuous	Continuous
Response	Angular Rates	10°/sec.	60°/sec.	60°/second	90°/second	60°/second	60°/second	60°/second
	Translational Rates:	0 - 30 knots	0 - 200 knots	0 - 200 knots	150 - 600 knots	0 - 10 knots (relative to lead)	150 - 600 knots	0 - 200 knots
Special Effects • Desired items not required for basic task		Not Required	• Fog • Haze • Reduced Ceiling • Visibility restriction	• Fog • Haze • Reduced Ceiling • Visibility restriction	Not required	Not required	• Ground fog • Clouds	• Fog • Haze • Reduced ceiling • Visibility restrictions

that will provide the greatest degree of versatility. A digital computer image generator was suggested as the most versatile system since the image, generated according to a predefined math model, is limited only by the system constraints and the programmer's imagination. Such a system does not require difficult-to-make transparencies or film strips for a given situation. For aerobatics and airwork, the study recommended a point-light-source projection of the earth and sky with minimum amount of detail. Formation flight training should be implemented by one of three elementary systems:

1. Scale model using a CCTV system
2. Lissajous pattern generator
3. Digital image generator

In order to have a versatile system for the ETSS facility visual experimentation it is necessary that all aspects of flight be considered in the training curriculum. This implies a visual system with a 165-degree vertical field of view and a 240-degree horizontal field of view.

APPENDIX G

MARINE VEHICLES

Marine vehicles include:

a. Surface displacement vessels ranging from fast, lightweight patrol boats to large aircraft carriers.

b. Surface effect vehicles or hover-craft ranging in size from the SK6 to SRN4.

c. Subsurface vessels or submarines ranging in size up to the new nuclear attack submarines.

1. MOTION CHARACTERISTICS OF MARINE VEHICLES.

When steaming through rough seas a ship is subjected to water forces which compel it to oscillate in all possible directions, and these motions are repeated more or less periodically. The ship rolls and pitches about longitudinal and lateral axes in a horizontal plane, and yaws about a vertical axis. It also performs three translational motions: the center of gravity heaves vertically, surges longitudinally, and sways laterally. The actual movements are usually a complicated combination of all six motions.

A survey of available literature produces a useful guide to ship motion during stormy weather. These data are reproduced in Tables 20 and 21 (Pages G-2 and G-3), Figures 15 through 19 (Pages G-4 through G-8). The findings from these data reveal the facts discussed herein.

The rolling period for the majority of vessels lies between 4.5 and 33 seconds. The maximum roll angle noted in the vessels was 27 degrees. It should be noted that for some vessels, landing craft in particular, an angular acceleration of 49 deg/sec^2 has been recorded. The pitching period for the majority of vessels lies between 3 and 7 seconds. The maximum pitch angle noted was 10 degrees, with the majority lying about 5 degrees. It should be noted (Figure 17, Page G-6) that the maximum pitch angle occurs when the wavelength equals the ship hull length; the pitch angle in this case may be four times the maximum wave slope. For landing craft, pitch angles of 30° have been recorded. The heave and dip characteristics of a ship are dependent on wave height. From

TABLE 20. ROLLING PERIODS AND ANGLES ON TYPICAL VOYAGES

SHIP	TYPE	NATURAL ROLLING PERIOD (Seconds)	ACTUAL ROLLING PERIOD (Seconds)	MAXIMUM ROLLING ANGLE (Degrees)
Q.S.S. Berengaria	Liner	21.0	20 to 30.6	8.2
Q.S.S. Maretania	Liner	15.8	17 to 33	12.9
Q.S.S. Montcalm	Liner & Cargo	17.0	16 to 19	17.4
T.S.S. Oroya	Liner & Cargo	16.[illegible]	9 to 18.3	13.8
T.S.S. Oropesa	Liner & Cargo	1[illegible].5	11.8 to 14.	27.8
S.S. London Marine	Fast Cargo	13.8	13.8 to 20.2	10.1
S.S. San Tirso	Tanker	2.2	4.6 to 10.4	18.4
S.S. San Gerardo	Tanker	9.3	9.5 to 11.2	24.0
S.S. San Alberto	Tanker	7.8	9 to 12	28.0

TABLE 21. CHARACTERISTICS OF MOTION FOR U. S. NAVAL VESSELS

VESSEL TYPE	PERIOD OF ROLL(SEC)	AOR (DEG)	POP (SEC)	AOP (DEG)	ACC. (g)
Destroyer	9.5	25	5	5	.26
LCI	4.5	25	3	5	.21
LCT	5.0	15	4	3	.19
Destroyer Escort	[illegible].0	25	5	5	.14
Heavy Cruiser	12.	20	7	4	.14
Carrier	16.0	15	7	4	.13
Light Cruiser	[illegible]	[illegible]	7	4	.13
Escort Carrier	[illegible]	20	7	4	.12
Battleship	14.0	12	6	3	.12
Transport	14.0	25	7	4	.08
Submarine	5-11	27	3-7	4	NA

AOR - Angle of Roll

POP - Period of Pitch

AOP - Angle of Pitch

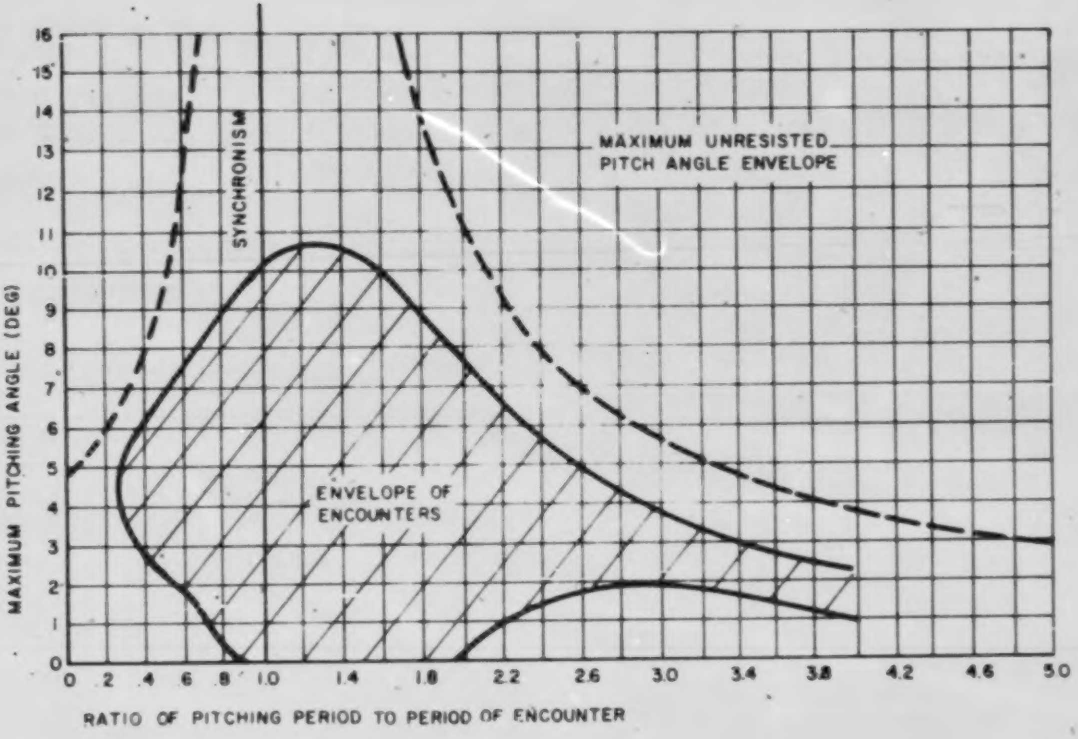


Figure 15. Pitching Angle Recorded at Sea in Merchant Vessels on Ocean Voyages in Winter

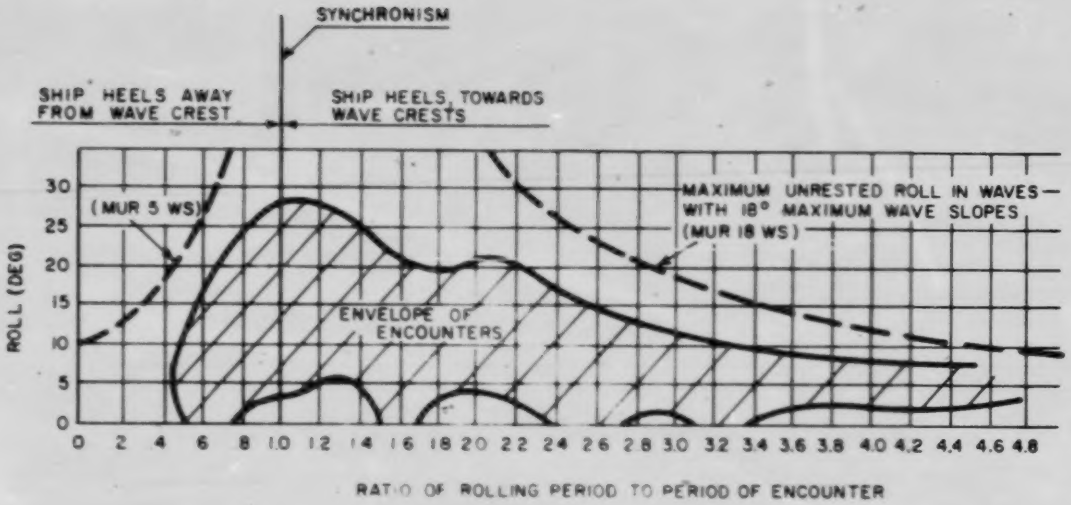


Figure 16. Roll Angles Recorded in Various Ships During North Atlantic Crossings in Winter

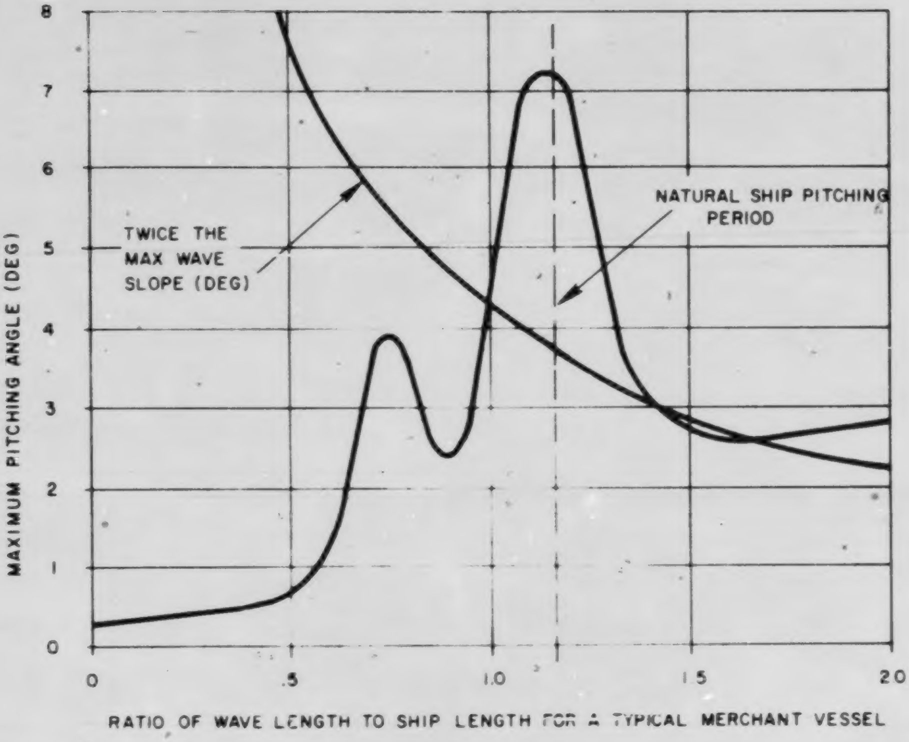


Figure 17. Maximum Pitch Angle of Ships Versus the Ratio of Wave Length to Ship Length

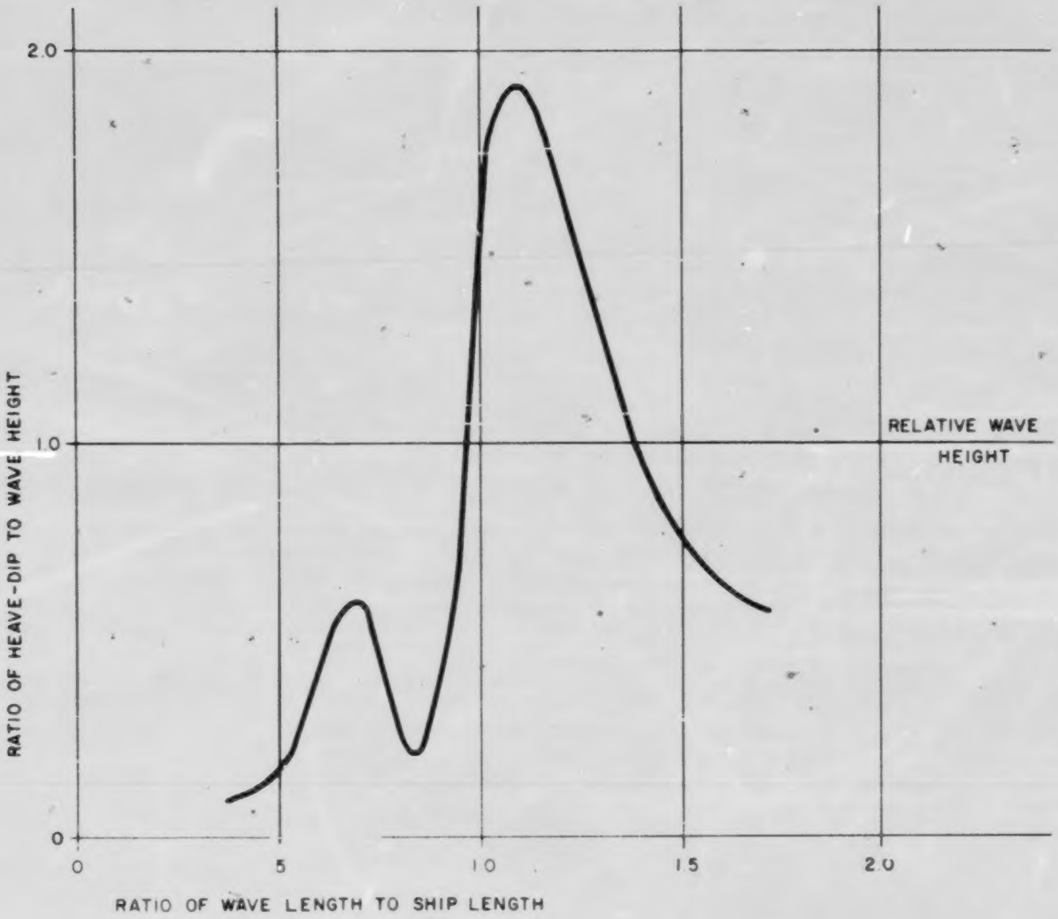


Figure 12. Heave-Dip Characteristics for a Typical Merchant Vessel

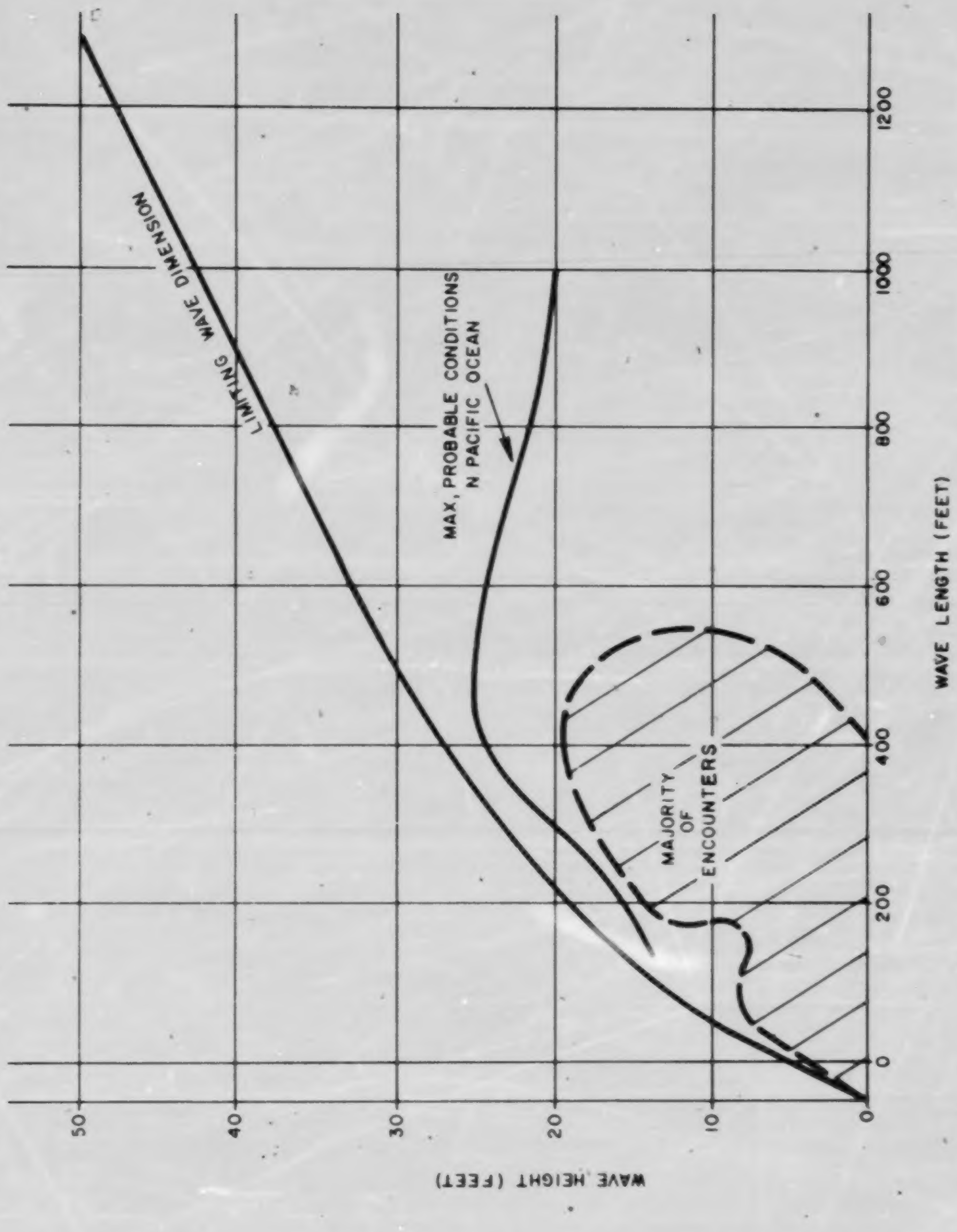


Figure 19. Typical Wave Characteristics for the North Pacific Ocean

Figure 18 (Page G-7), it should be noted that, at the synchronism point, the heave or dip of a vessel may be almost double wave height. Wave height and length are functions of many parameters, too numerous to be detailed in this report, and Figure 19 (Page G-8) shows typical wave characteristics for the North Pacific Ocean, together with the curve for theoretical wave dimensions.

For these conditions the maximum acceleration in heave at a wave speed, relative to the hull, of 20 kt would be about 0.07 g.

Yawing, in a ship, usually takes place with such a slow acceleration that it is almost imperceptible. In these conditions a visual cue for yaw is best appreciated. However, small craft with flat bottoms, such as assault landing craft, can have a pronounced yawing motion when broaching in the waves. In these circumstances the yaw rate may be as high as 60 degrees/second. Again, the visual representation of the total angle traversed, together with the onset of the yaw provided by the motion system will induce a realistic simulation of severe yawing.

The translational motion of ships generally occurs with low values of acceleration, unless the vessel's extremities are considered. Again, the onset of the cue would have to be provided because of large magnitudes of motion in heave, dip, surge and drift.

A vessel will occasionally slam when driven through rough water. This means that the forward section of the hull receives a violent blow that causes the hull to shudder with a rapid vibration having a period of less than a second. At the instant of slam, a loud report is heard throughout the ship. Studies of slamming have shown that accelerations as high as 4g can occur. The duration of the acceleration is short, in the order of 0.25 seconds.

In summarizing the characteristic motion requirements for naval vessels, angular motion, yaw excepted, should be fully represented. The effect of roll and pitch is a destabilizing influence on the persons manning the vessel. A system that returns to the neutral position subliminally would provide a very false sensation of roll and pitch excursions. Angular acceleration should be about 50 deg/sec^2 with angular velocities 7 deg/sec in roll, 3 deg/sec in pitch, and an initial yaw cue of 60 deg/sec. The translational motions due to their magnitudes are best represented by providing a motion cue onset backed with a visual cue of the continuous motion. Due to slamming requirements, the onset of acceleration may be as high as 4g.

2. VISUAL CHARACTERISTICS OF MARINE VEHICLES. Marine vessels may operate in a number of roles; each one demanding different characteristics in the visual simulation system. A list of these operating roles includes:

a. Vessel in passage by itself

b. Vessel in passage accompanied by other vessels

c. Vessel in harbor approach

d. Vessel docking alongside another vessel or jetty

e. Vessel approaching beachhead and leaving beach

f. Submarine submerged and using periscope under situations corresponding to a, b and c.

g. Submarine running on surface under conditions corresponding to a, b, c, and d.

h. Vessel in combat with target

This list is applicable to day, night and fog-limited operating conditions.

In the first role--no other vessels or land in the visual scene--the image content is composed of water and sky separated by the earth's horizon. Unless the visual system is being used to depict the effect of different weather patterns, the sky detail can be ignored. The sky is blue becoming lighter toward the horizon. The movement of the horizon should be coordinated with ship movement and with any wave motion.

The appearance of surface waves, if portrayed, may cause severe technical problems. If there is no requirement for a dynamic wave motion, the visual requirements can be met with a point-light-source projector, sea-sky transparency and a pitch-roll transparency drive system. The problem arising from the appearance of significant waves in the visual scene may be surmounted in a number of ways. It is important to remember that simulator motion must be coordinated to the visual wave movements through the combined transfer function of the vessel and the wave describing function.

This requirement rules out any simple film projection or reconstruction system. A VAMP* system could be used as long as the direction of approach to the waves could be suitably restricted. In this application, the wave amplitude information could be placed together with the velocity and position information on an expanded sound track alongside the picture. Large directional deviations cause the waves to become very steep or, in the opposite sense, to become innocuous ground swells.

A theoretical approach would be to use a three-dimensional transparency reconstructed of the wave image, with the sky separately superimposed on the horizon. Systems such as this are limited by the CRT characteristics to a resolution of 2000 lines per inch on the face of the tube**. At low elevations, however, the resolution is relatively poor using an 18-inch-square transparency at a scale of 600,000:1 (see Ref. 39). Reducing the scale to 100,000:1 with 2000 lines/inch would achieve a theoretical resolution of 50 inches. An 18-inch-square transparency would cover an area about 28 statute miles square. However, since the wave shape has to be generated, about 8 lines of information per wave are needed. This would result in an effective system resolution of about 33 feet. For a vessel in passage, with wave lengths of about 300 feet, this may be acceptable. The transparency would be scanned with velocity corresponding to the vector sum of the vessel velocity plus the velocity of the waves - both measured in a common reference frame. Since the area of navigation is relatively small, the edge of the transparency would be reached in a relatively short time. However, since the ETSS is concerned with human factors research, it is felt that this limitation on the system can be justified in view of the fact that the experiments will not be of long duration.

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* Trademark, Link Division of the Singer Company

** Ferranti Data Sheets: Micro spot Cathode Ray Tubes, 5G/7 and "Resolution to its measurement."

One further approach is to use a digital electronic generation of the wave images using a mathematical representation of wave motion. A math model such as this could be used for both the visual and motion signal requirements. Since the wave is a complex form, a large number of lines are needed to describe its shape. This immediately puts a limitation on the fidelity of the resulting picture, since the electronic image generators are generally limited to relatively few describing lines. However, as computer-visual technology improves, so will picture definition.

At this point, it should be stressed that any visual scene portraying waves synchronized to vessel motion will be a very expensive system.

For vessels in passage accompanied by other vessels, all the constraints concerning vessels in passage apply. However, an additional constraint is added since there are other dynamic vessels in the pictorial scene. The scene image content can range from other vessels coming over the horizon towards the vessel being simulated, to another ship stationkeeping on the simulated vessel. This implies that there is dynamic motion between two or more vessels. Since the prime image content is the other vessel, the detail of the sea and sky need not be reproduced with a high level of fidelity.

The angle of view required for such a system may be described as the view from the bridge of a ship. Except for very close-in maneuvering there is little need to look above the horizon. When keeping station on another ship it is rarely necessary to look down at an angle in excess of 60 degrees. The horizontal field of view, due to ship passage, becomes quite extensive and may be approximated by a horizontal field of view of 240 degrees. At least two methods are applicable to this operating role. The first one, described briefly in the previous section is the digital generation of electronic images. The images generated may be filled-in line drawings of the surrounding vehicle since the training value is derived from the relative dynamics of the vessels and not the vessel detail. A recent analysis of the display generation requirements has resulted in a carrier landing and takeoff line drawing system being developed for NTDC by the Evans & Sutherland Corporation. Admittedly, the more detail there is, the more easily the visual display is accepted by the subject. A typical presentation of the digital visual scene is depicted in Figure 20 (Page G-13). By suitable manipulation of the math model the image dynamics may be changed readily.

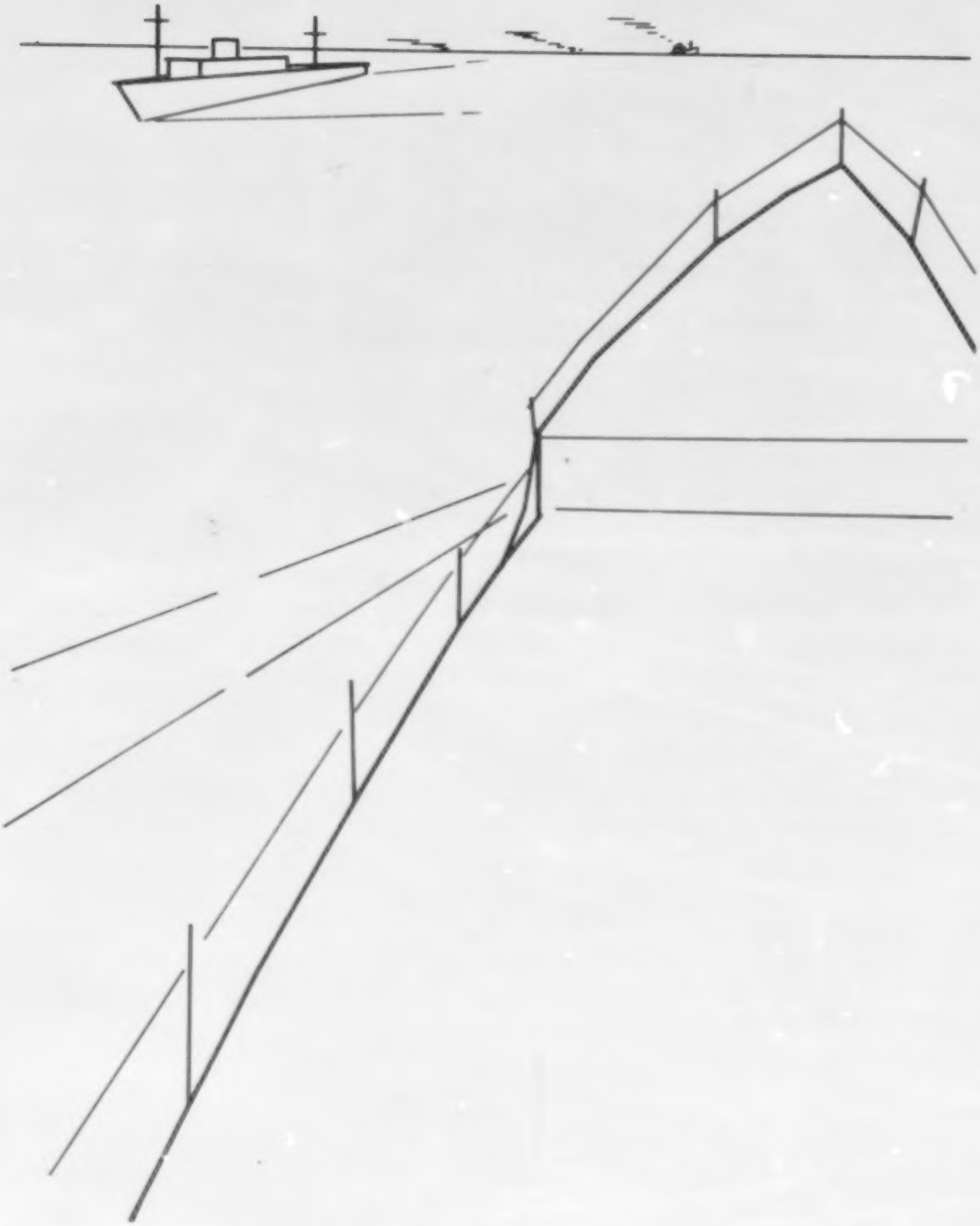


Figure 20. Typical Digital Visual Scene for Surface Ships

The remaining method that fulfills the requirements of this operating role is a camera-model system. Either of two types of camera-model system may be used, depending on whether there is more than one vessel in the image content.

The first approach assumes that there is only one vessel in the visible area of the ocean. This technique uses a single model of the other ship and a TV camera probe which has zoom and track capabilities. The TV camera also has the capability for allowing a change in ship's heading. Roll and pitch are considered unimportant quantities since there is no wave motion depicted. At distances from the model where perspective angle changes are small, the zoom capability is used to simulate the two vessels approaching each other. As the change in the perspective angle becomes significant, the TV camera starts to track in towards the model. The effect of the model changing heading is provided by mounting the model on a turntable. Figure 21 (Page G-15) shows a typical layout of the system. To allow sufficient detail on the model a scale of about 480:1 is suggested (40 ft/in). The plastic models available in retail stores are very satisfactory. The ocean horizon is generated by the intersection of the plane carrying the vessel model and the sides of the device.

The second approach, which allows multiple vessels to maneuver, is similar to the first. However, the camera, equipped with a zoom lens, is only allowed to rotate in azimuth with translational movement eliminated. Suitably scaled models of the maneuvering vessels are placed on the surface of the device and are controlled by "crabs." These crabs operate, under computer control, beneath the surface of the device controlling the models by virtue of the attraction of two magnets (one magnet is on the model base and another on top of the (controlling crab). Figure 22 (Page G-16) illustrates the basic concepts of such a visual system.

The other visual system techniques described in Appendix J, with the possible exception of VAMP, are eliminated by virtue of relative motion between observer and other vessels. Providing the field of view and the dynamics of the situation are suitably restricted, and the angular deviations from the nominal path limited, the VAMP system may be used.

A vessel maneuvering in the approaches to a specific harbor has a distinct visual environment. The coastline is in sight with prominent features easily visible from the vessel.

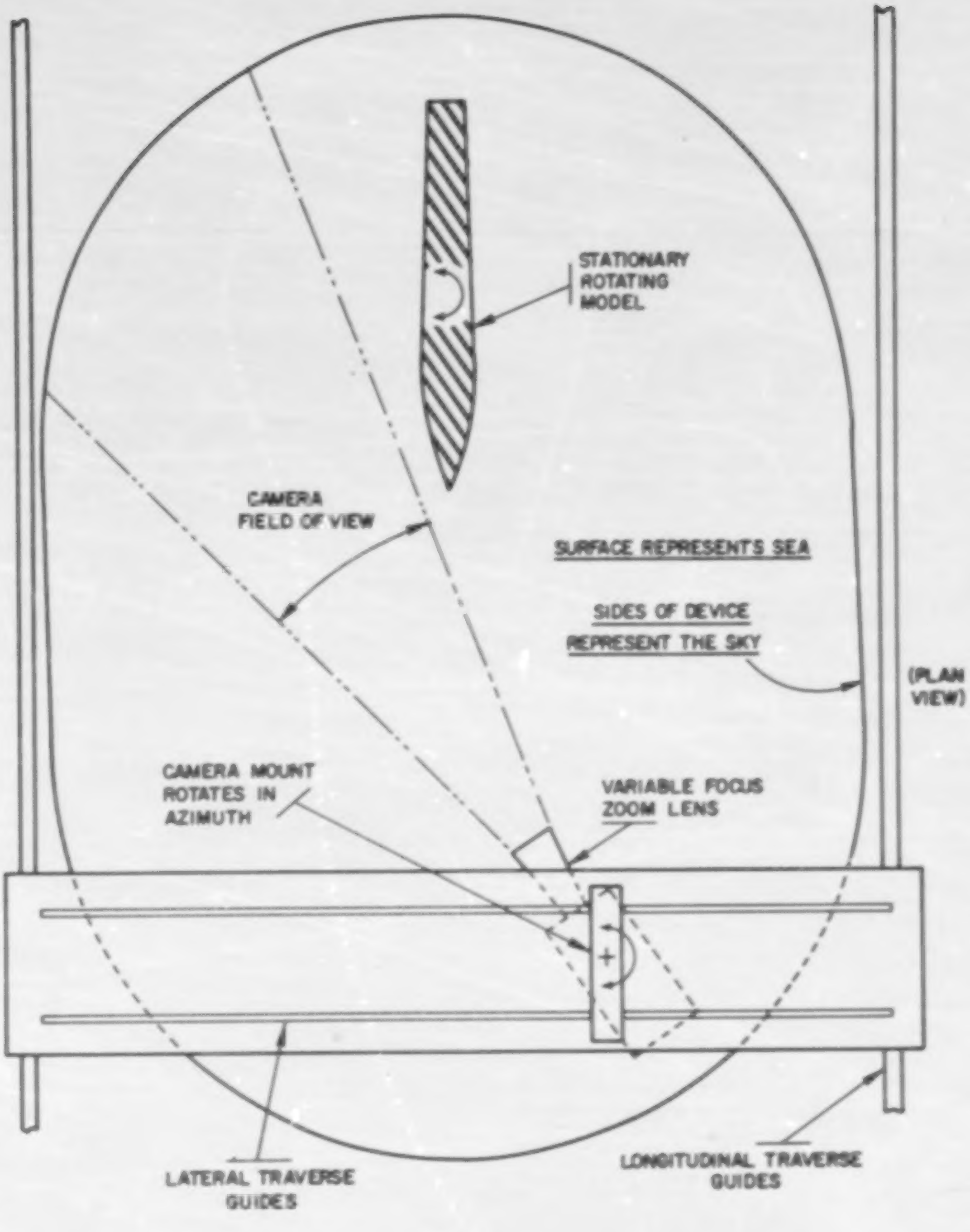
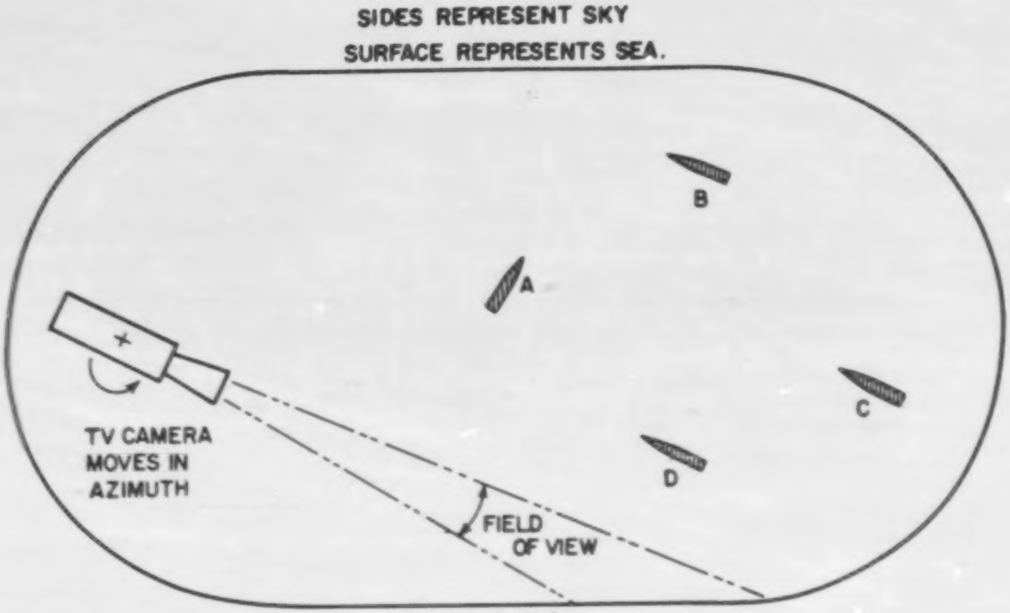
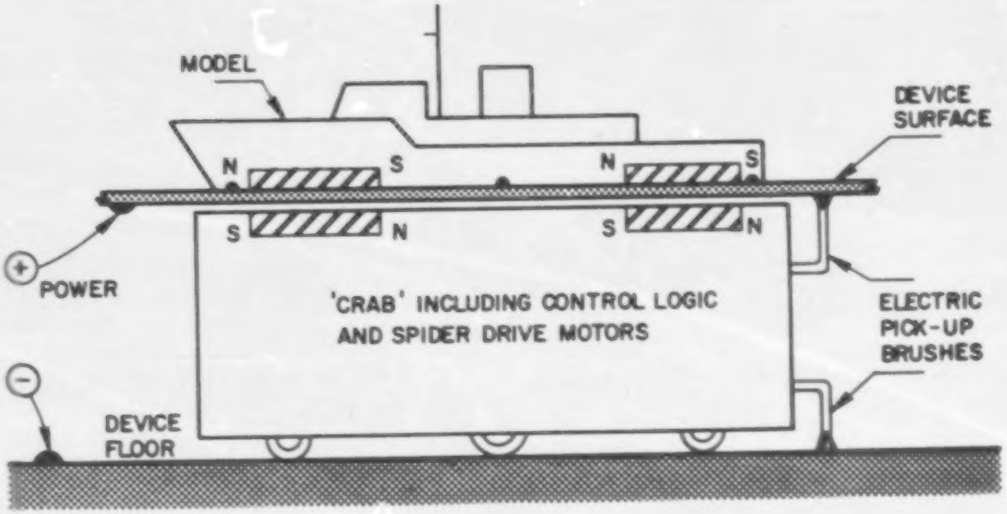

STATIONARY
ROTATING
MODEL
CAMERA
FIELD OF VIEW
SURFACE REPRESENTS SEA
SIDES OF DEVICE
REPRESENT THE SKY
(PLAN
VIEW)
CAMERA MOUNT
ROTATES IN
AZIMUTH
VARIABLE FOCUS
ZOOM LENS
LATERAL TRAVERSE
GUIDES
LONGITUDINAL TRAVERSE
GUIDES

Figure 21. Typical Camera-Model System Layout


SIDES REPRESENT SKY
SURFACE REPRESENTS SEA.
B
A
C
D
TV CAMERA
MOVES IN
AZIMUTH
FIELD
OF VIEW

(PLAN VIEW)

MANEUVERING MODELS A,B,C,D


MODEL
DEVICE
SURFACE
N
S
N
S
S
N
S
N
POWER
'CRAB' INCLUDING CONTROL LOGIC
AND SPIDER DRIVE MOTORS
ELECTRIC
PICK-UP
BRUSHES
DEVICE
FLOOR

(PARTIAL PROFILE)

Figure 22. Multiple- Model Camera-Model System Layout

The approach path to the harbor is generally defined by a relatively narrow channel. The channel is marked by conspicuous buoys, beacons, and stakes which use lights and colors for identification. The channel is used by other vessels.

If the constraint of other vessels in the visual scene having a responsive maneuvering capability is waived, then the choice of the visual system may be made from any of the following:

1. VAMP visual system
2. Transparency reconstruction system
3. Camera-model system with CCTV
4. Electronic image generation

These systems differ only in their technical approach and image definition. A VAMP system approach would require that the deviations from the desired path not be excessive in either heading change or lateral deviation. Electronic image generation would provide greatest versatility, but at the expense of a large programming task and inferior definition.

As soon as the constraint of other vessels in the visual scene is imposed, the choice of the visual system is much more limited. For a system portraying other vessels which have a responsive maneuvering capability, the choice is between an animated camera-model system and an electronic image generation system.

Particularly important in the role of navigation is the representation of color navigation marks and the correct representation of area navigation lights. All the factors previously given for waves hold true for this operational role as well.

Vessel berthing places a premium on good seamanship and good ship control. During an operation of this type, it is of ultimate importance for the ship's officer to be able to estimate distance and velocity between his ship and the vessel, or jetty, along which he wishes to berth. In normal situations, with no wind or current, the approach path is very narrow and well defined. However, some situations involving an off-shore wind or adverse current result in the vessel taking up large angles relative to the normal straightforward approach.

An operation of this type generally requires a wide angle of clear vision. The vertical component need not be more than about 90 degrees below the horizon and only about 5 degrees above it. However, the horizontal angle should extend from 10 degrees off the bow and continue, through the bow, round towards the stern and terminate 10 degrees off the stern. This may be depicted as in Figure 23 (Page G-18).

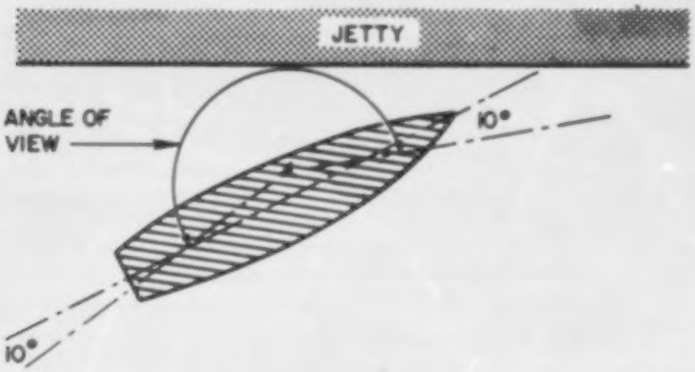


Figure 23. Typical Berthing Operation

This results in a visual field of view of 200 x 95 degrees. Since the visual requirements pertain to the relationship between a stationary vessel or jetty and the simulated vessel, a number of solutions to the problem exist. These may be summarized as:

1. Electronic generation of the visual image.
2. Camera-model system using CCTV
3. VAMP system

The VAMP system leads the field as far as image quality is concerned. However, as soon as the deviations from the theoretical ideal path become significant, the perspective distortion becomes large and disturbing. This situation could exist if the ship were docking with an off-shore wind and was allowed to swing to the bow rope or was allowed to swing with the bow pressing on the jetty. A camera-model system allows the greatest flexibility as far as versatility and image fidelity is concerned. However, it cannot compete with the image quality of a motion picture film. A system employing digital generation of an electronic image has the greatest convenience, in that there is no specific hardware associated with a given visual requirement. The berthing maneuver can be represented by a composite line drawing, which would show the ship's bow and the approaching dock. As the dock becomes nearer and the image becomes larger, detail could be added to give an air of reality to the visual scene. This sytem would be the most versatile but may not produce the highest fidelity. It can be assumed that wave action would not be significant since the majority of berthing operations occur in sheltered waters.

The case of an assault craft approaching an enemy-held beach is an example of a small vessel operating in coastal waters with a large amount of wave action. In an NTDC study (42) concerning the feasibility of an assault boat coxswain trainer, special emphasis was placed on craft control, in conditions where wave action is significant. This implies that the visual system should be capable of producing a specific wave system. Also, it should be understood that this wave action, in the visual scene must be synchronized with the motion system supporting the trainee station.

The same problems as stated previously exist for this visual requirement. Since it is possible for an assault boat to broach during its run in towards the beach, a VAMP system must be ruled out. The resultant distortion of the visible waves during a heading change of 90 degrees would be intolerable and totally unrealistic even if the VAMP had the necessary capability. Therefore, the choice lies between a three-dimensional transparency reconstruction system and a system employing digital generation of the electronic image. Both systems would be expensive in terms of hardware and programming. During the run in, the coxswain requires a field of view extending from abeam on the portside through the bow to abeam on the starboard side. Since he is at a low elevation with respect to the horizon, a vertical field of view of 20 degrees depression and 30 degrees elevation should suffice. Thus the visual system requires an angular field of 180 horizontal degrees and 50 vertical degrees. The yaw rates of assault vessels, as discussed previously, are in the order of 60 degrees per second, with angular accelerations up to 50 degrees/sec^2. Translational velocities range from zero to upwards of 30 knots.

A submarine submerged and running at periscope depth experiences very little motion due to surface wave action. Due to the very small effect of wave action, submarine roll and pitch will be eliminated and the surface will be treated as a calm sea.

The angle of view subtended by a submarine periscope generally does not exceed a solid angle of 60 degrees. In order to achieve the utmost versatility in a visual system for the ETSS, the periscope visual system should use as many components of existing systems as possible. For this reason, it is recommended that periscope visual system be a two-tier arrangement. The lower level would contain an elementary periscope at the subject station which would view the visual scene in the upper tier. The upper tier would contain any one of the visual systems described previously for the operating roles. The visual scene depicted in the upper tier would take its inputs from computer variables corresponding to:

1. Submarine speed
2. Submarine heading
3. Submarine depth
4. Periscope extension
5. Periscope magnification
6. Azimuth data from periscope mount
7. Periscope elevation angles
8. Target dynamics

The illusion of raising and lowering the periscope would be restricted to the lower tier only. A telescopic tube would contain any relative movement, allowing the viewing lens to be stationary to the visual scene. Two conceptual approaches to such a system are shown in Figures 24 and 25 (Pages G-21 and G-22). Internal optics within the elementary periscope tube would be fixed. The effect of elevation, magnification, etc., would be simulated by a change in the visual scene.

It should be noted that this system may use any of the visual systems described in the foregoing sections, providing that their limitations are taken into consideration.

A submarine running on the surface is virtually akin to a surface vessel maneuvering on the surface. The only real difference is the immediate (near) scene. This should resemble

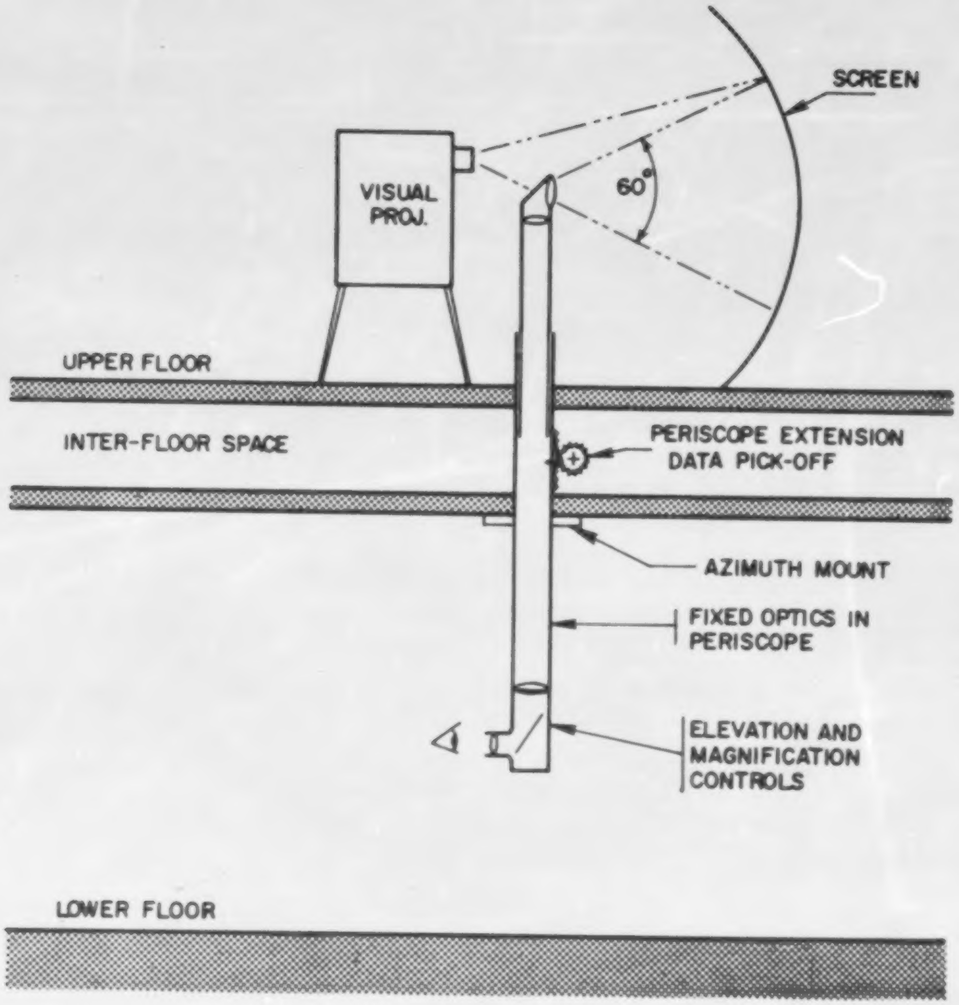

SCREEN
VISUAL PROJ.
60°
UPPER FLOOR
INTER-FLOOR SPACE
PERISCOPE EXTENSION DATA PICK-OFF
AZIMUTH MOUNT
FIXED OPTICS IN PERISCOPE
ELEVATION AND MAGNIFICATION CONTROLS
LOWER FLOOR

Figure 24. Periscope Visual System

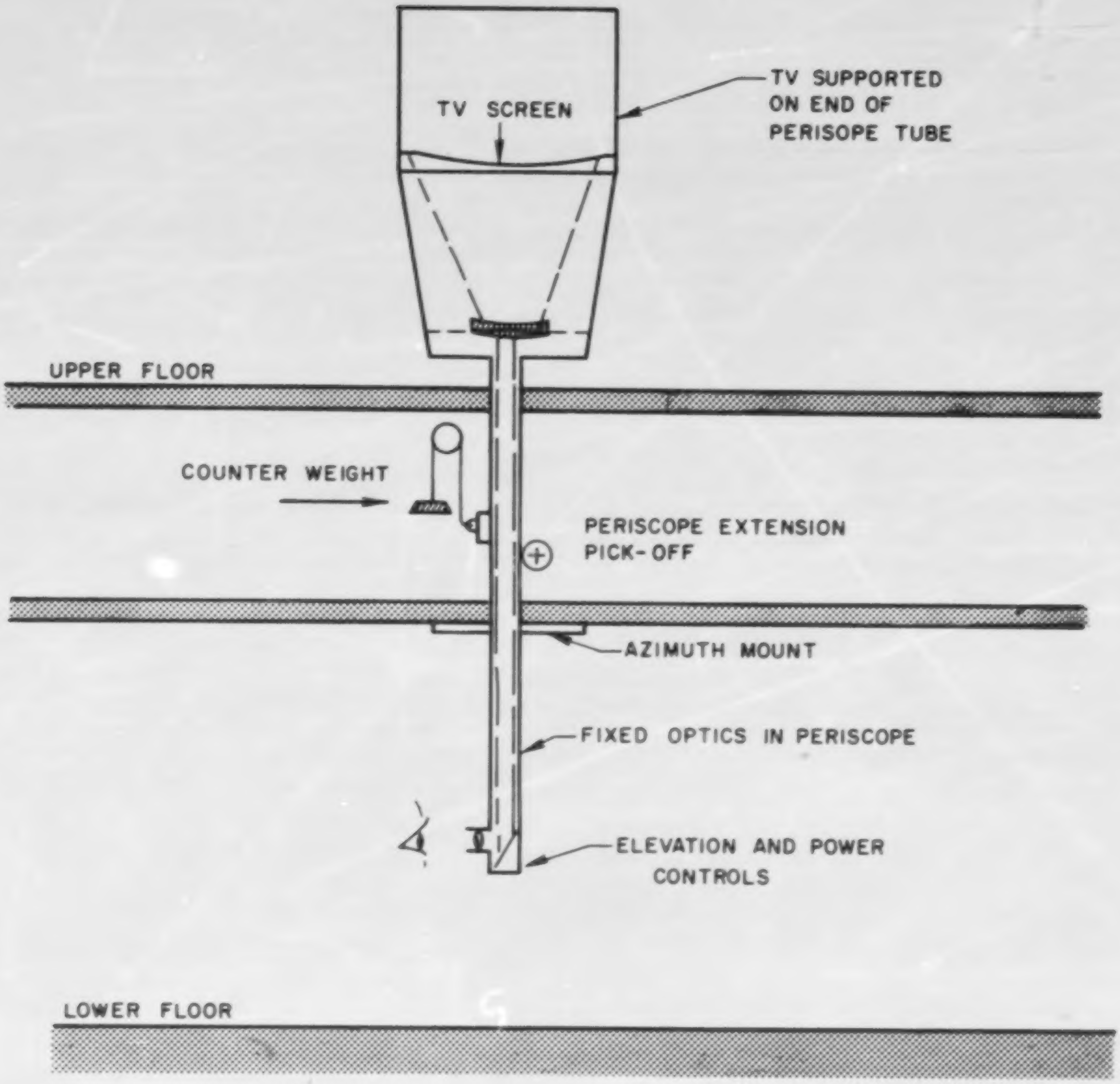

TV SUPPORTED ON END OF PERISOPE TUBE
TV SCREEN
UPPER FLOOR
COUNTER WEIGHT
PERISCOPE EXTENSION PICK-OFF
AZIMUTH MOUNT
FIXED OPTICS IN PERISCOPE
ELEVATION AND POWER CONTROLS
LOWER FLOOR

Figure 25. Alternate Periscope Visual System

a submarine and not a surface vessel. Another possible difference is the lower elevation above the sea of the conning tower when compared to the bridge or deck of a conventional surface vessel. The principal effect of a lower viewing elevation is that the horizon appears closer to the viewer.

A vessel engaged in combat with a target represents the most complex operating role of a simulator. The visual system must not only portray other vessels and the land masses, but the effect of projectiles hitting the water, or exploding on the target. The visual system should be equally capable of representing the view from the command position or the view from one of the weapon stations -- gun turret or missile launcher.

The visual scene for this area of operations may have the following characteristics:

1. Seascape, including wave action
2. Land mass
3. Other vessels maneuvering in scene
4. Aerial targets
5. Targets stationary or moving on land mass
6. Effect of exploding projectiles
7. Water spouts caused by projectiles hitting the water

A very sophisticated, complex, and expensive visual system would be required to meet these requirements. An approach such as this would price the visual system for the ETSS beyond a reasonable level. What is required is a system that gives the elemental impression of the essentials of a combat situation.

Generally speaking, the smaller the number of components involved in a visual system, the easier the system will be to maintain and to use. For example, there would be only one film to process for a film projection system, only two slides to make for a transparency reconstruction system, only one digital program to write for a digital image generator and only one model to build for a camera-model CCTV system. Any mixing of systems produces a system that is ungainly to manage -- particularly for experimentation by the staff of the ETSS. The only system that can encompass all the items in the previous list of characteristics and yet retain system simplicity is a visual system utilizing a digital electronic image generator. By today's standards, even a digital electronic image generator would be extremely expensive and quite possible beyond the state of the art. The visual scene generated would be cartoon-like in character in comparison with the real world.

The field of view requirements for this situation are quite varied. If the ship commander is under aerial attack, a field of view of 190 horizontal degrees by 120 vertical degrees (+90, -30) may be required. For a gunnery station on the same vessel, the field of view from the weapon station is restricted and a field of view corresponding to a solid angle of 60 degrees may suffice.

An important aspect of navigation on the open sea is that of collision avoidance. In general, the sooner the vessel's commander can see another vessel, the sooner he can take the appropriate action. Since a synthetic visual system is being used for the visual scene, the question of minimum resolving capability is an important one because it determines how far away another vessel may be observed. If we take a case of a ship steaming directly towards the observer, with an overall dimension envelope of 100 x 100 feet, and placed directly on the horizon of the observer, then the requirements for resolving power of the visual system are shown by Figure 26 (Page G-25). This represents a minimum performance requirements.

Since the viewpoint in any vessel is seldom more than 150 feet above the sea, the visual system should have a resolution of at least 5 minutes of arc. This would allow a typical merchantman, steaming head on to the observer, to be seen on the horizon. For a submarine commander, with periscope raised 2 feet above the water, this would allow details larger than about 15 feet in dimension to be observed on the horizon.

The definition of the minimum image size for navigation lights on vessels and shore installation is not related to visual resolution. So long as the light source has sufficient energy, the eye is capable of observing that light source no matter how small it becomes. In a motion picture film the emulsion captures the light source image directly on the film. Upon projection with good optics the light source is reproduced as a close representation of the real-world source. However, the smallest element in a TV system is one-line element -- a group of color dots on a given raster line; therefore, distant lights, if portrayed, may appear to be physically larger than the actual lighting installation.

Table 22 (Page G-26) summarizes the visual requirements for naval vessels.

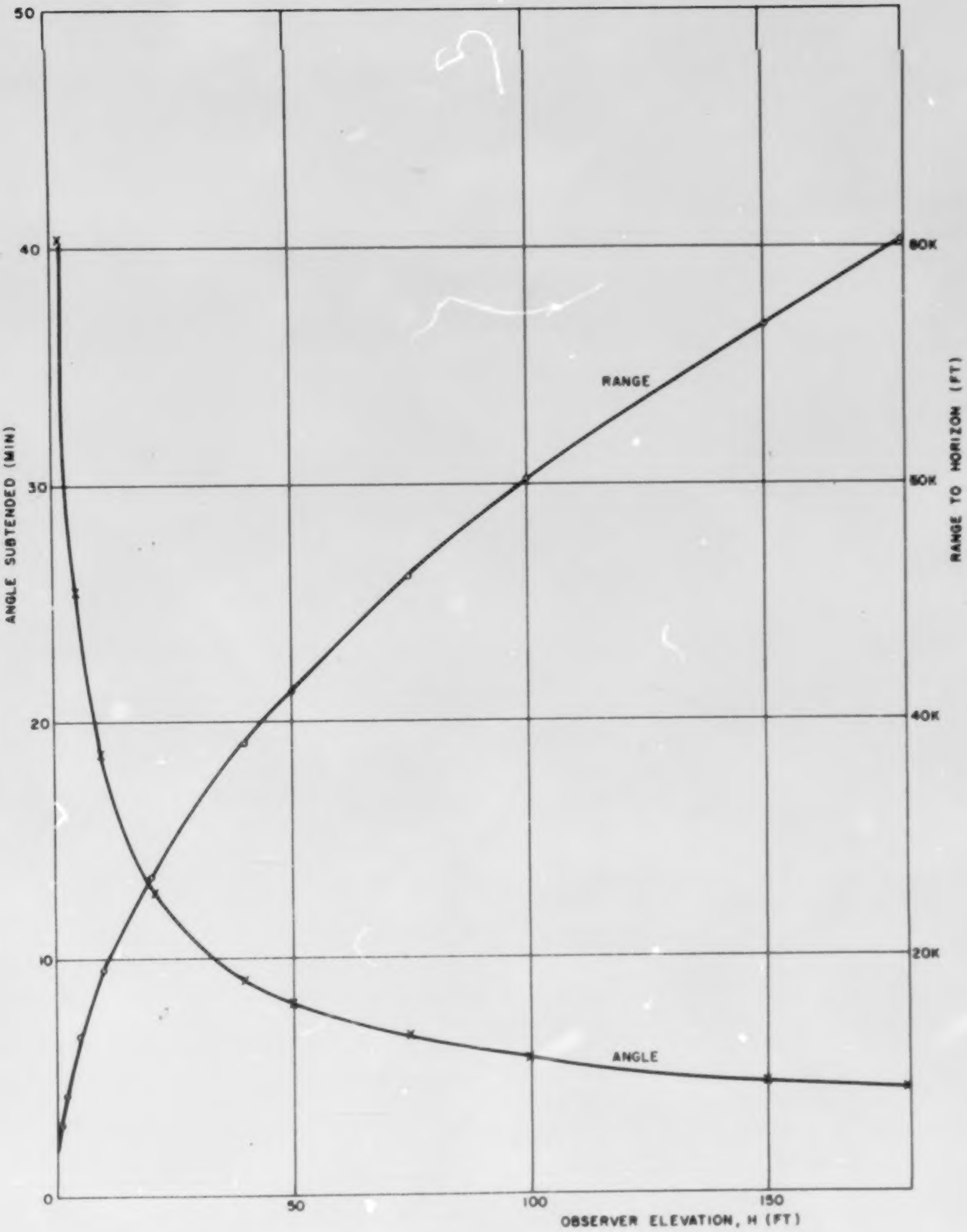


Figure 26. Minimum Resolution Required to View Average Ship On Horizon

TABLE 22. VISUAL REQUIREMENTS FOR NAVAL VESSELS

PARAMETER	VESSEL IN PASSAGE WITH NO OTHER VESSELS	VESSEL IN PASSAGE WITH OTHER VESSELS	VESSEL IN HARBOR APPROACH	VESSEL DOCKING ALONGSIDE JETTY OR ANOTHER VESSEL	VESSEL APPROACHING AND DEPARTURE FROM BEACH-HEAD	SUBMARINE SUBMERGED, CATEGORIES A,B,C	SUBMARINE ON SURFACE, CATEGORIES A,B,C,D	VESSEL IN COMBAT
	A	B	C	D	E	F	G	H
FIELD OF VIEW: UP	5	5	5	5	30	30	As for A,B,C,D	90
DOWN	60	60	60	60	20	30		30
LEFT	120	120	120	100	90	30		95
RIGHT	120	120	120	100	90	30		95
DESIRED RESOLUTION (ARC MINUTES)	4-5	4-5	3	6	4	6	B > 8	2 < B < 20
HIGHLIGHT BRIGHTNESS^1 (FOOT LAMBERTS)	B > 8	B > 8	B > 8	B > 8	B > 8	B > 8	B > 8	2 < B < 20
CONTRAST: BLACK AND WHITE	25:1	25:1	25:1	25:1	25:1	25:1	25:1	25:1
COLOR^2	15:1	15:1	15:1	15:1	15:1	15:1	15:1	15:1
IMAGE CONTENT * Desired items not required for basic task.	Horizon Sky* Waves* Portion of simulated vessel	Horizon Sky* Waves* Portion of simulated vessel Vessels moving in the water under computer control	Horizon Sky* Seascape Portion of vessel Lighthouses Buoys Beacons Other vessels* Shoreline Obstructions* Lights	Harbor detail Other vessels Obstructions Portion of vessel	(As per A,B,C) Shoreline *Gun flashes *Other vessels	(As per A,B,C)		Other vessels Gun flashes Water splash Targets Land mass Seascape
PERFORMANCE LIMITS X	100 miles	30 miles	30 miles	2000 feet	10,000 feet	16,000 feet		30 miles
Y	100 miles	30 miles	30 miles	2000 feet	10,000 feet	16,000 feet		30 miles
Z	60 feet	60 feet	60 feet	-	20 feet	-		60 feet
Roll (Degrees)	60	60	60	-	60	-		60
Pitch (Degrees)	20	20	20	-	60	-		20
Yaw (or Heading) (Degrees)	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous		Continuous
Response								
Max Angular Rates (Deg/sec)	60	60	60	20	60	10		60
MaxTranslational Rates: X	200 ft/sec.	200 ft/sec.	30 ft/sec.	10 ft/sec.	50 ft/sec.	70 ft/sec.		200 ft/sec.
Y	20 ft/sec.	20 ft/sec.	20 ft/sec	-	20 ft/sec.	20 ft/sec.		20 ft/sec.
Z	20 ft/sec.	20 ft/sec.	20 ft/sec	-	20 ft/sec.	20 ft/sec.		20 ft/sec.
SPECIAL EFFECTS	*Fog *Haze	Night-time *Fog *Haze	Night-time *Fog *Haze	Night-time *Fog	Night-time *Fog	Night-time *Fog		Night-time *Fog *Haze

* Desired items not required for basic task.

[1] For night-time activity brightness for lights 2 foot lamberts

[2] Contrast for night activity 25:1

APPENDIX H

LAND VEHICLES

1. This appendix considers the characteristics of land vehicles as they appertain to the motion and visual requirements. This classification of vehicles includes:

1. Tracked vehicles ranging from light personnel carriers to heavy battle tanks.

2. Wheeled vehicles ranging from staff cars to heavy duty cross-country trucks.

3. Trains or track-guided vehicles.

4. Surface effect vehicles or hovercraft ranging from a few tons to several thousand tons displacement.

Appendix D defines a modern requirement for an automobile simulator.

1.1 THE MOTION CHARACTERISTICS OF LAND VEHICLES. The dynamics of a land-based vehicle, with fixed controls, over a specific terrain at a specific speed is a function of the suspension dynamics, the nature of the terrain being traversed and any aerodynamic forces that may be present. The terrain traversed by these vehicles ranges from smooth highways to rugged cross-country paths. A vehicle crossing a specific terrain is analogous to a dynamic process with an input of white noise of a given power spectrum. The resulting outputs from the process are accelerations, velocities and positions pertaining to the axes of the vehicle. Since the vehicle is not rigidly constrained, there are six degrees of freedom noticeable at the driver's position.

Since the facility will not be conducting experiments on the discrete components of the vehicle (such as suspension systems), the motions to be considered are those transmitted by the vehicle structure to the subject. The many authoritative works studying the motion of road vehicles, extrapolated to include motion over random terrain, indicate that the equations of motion are as complicated as those for an air vehicle. Appendix E illustrates a typical set of equations for a generalized vehicle. Since the analysis of these equations consumes a large amount of computation time and general effort, a different approach to determining characteristic vehicle motions will be used, based on the accelerations measured in the vehicle.

The accelerations acting on a land vehicle are a function of the external forces or moments, and the vehicle mass or inertia. These include steady-state and momentary accelerations.

For a given vehicle the longitudinal acceleration is a function of tractive effort, coefficient of friction and the terrain grade. Of all the land vehicles, the high-performance automobile has the highest value of longitudinal acceleration with values recorded in excess of 1.0g. This is due to the actual coefficient of friction being in the order of 1.3 due to "cogging" between the tire and road surface. Similarly, the cornering ability of an automobile is, among other things, a function of the coefficient of friction. Thus the lateral acceleration for a racing car can exceed 1.3g. Tests performed with the SD45 locomotive showed that the maximum longitudinal acceleration was 0.222g with a maximum value of 0.263g in lateral acceleration.

In general, land vehicles do not translate vertically except in response to a disturbance in the terrain that causes a vertical acceleration. For a high-performance road vehicle at maximum acceleration, a 35% grade may result in a minimum vertical acceleration of about 0.26g. For the SD45 locomotive the maximum vertical acceleration was 0.13g.

The momentary accelerations measured during the traverse of variable terrain result in a power spectrum being generated. During the tests conducted by the U. S. Army Human Engineering Laboratory (43), a number of subjects were asked to drive an M60A1 tank over courses at the Aberdeen Proving Ground. The root-mean-square average acceleration tolerated by the drivers was about 0.5g, with maximum values of 2g to 3g being reached. The power spectra for tests on the Fort Knox driving range indicate that at 10 Hz the vibration power is about 0.3% of the maximum power, and that at 5 Hz the power is about 30% of the maximum power. For a train the maximum shock measured during freight car handling was 2g in the longitudinal axis.

Normally, a land vehicle is a relatively stable vehicle. Yaw, defined as the angle between the vehicle longitudinal axis and the free airstream direction, is generally small unless the vehicle is skidding. A skidding vehicle can experience almost unlimited yaw. However, it is not anticipated that the ETSS will have a requirement for simulating an excessively skidding vehicle. Air-cushion vehicles (ACV's) may require a crab angle of up to 17 degrees in a 30 kt wind at a ground speed of 100 kt.

During cross-country driving there may be occasions when the grade exceeds 100%, which corresponds to an angle of 45 degrees. The land vehicle under normal dynamic conditions does not experience pitch angles of much more than 20 degrees. Recent films of the MBT 70 taken during demonstration trials indicated a momentary pitch angle of about 40 to 50 degrees. As a result of the gradient, the roll angle may equal or exceed the gradient when the vehicle is driven traverse to the slope. Therefore, cross-country vehicles may experience roll angles of up to 40-50 degrees and trains may have track beds banked at up to 30 degrees.

Land vehicle motion requirements based on the foregoing considerations are tabulated as:

Longitudinal Acceleration	2.2 g (rms)
Lateral Acceleration	1.3 g (rms)
Vertical Acceleration	3 g (rms)
Pitch Angle	50 degrees
Roll Angle	50 degrees
Yaw Angle	20 degrees

1.2 The Visual Characteristics of Land Vehicles. A visual system for land vehicles has certain features that make it different from that for seaborne and airborne vehicles. Typical of the vehicle types are the following:

1. Passenger cars operating on roadways
2. Buses operating on roadways
3. Trucks carrying freight on roadways
4. Trains
5. Cross-country vehicles
6. Tanks

7. Air cushion vehicles
8. Non-articulated cross-country vehicles

The prime difference between the visual requirements for land vehicles and those for air or seaborne vehicles is that the visual horizon is generally very much closer.

For an analysis of the visual requirements, the categories of passenger cars, buses, trains, trucks and air cushion vehicles will be classified as one group, cross-country vehicles in another group and tanks in another. ACV's may also be classified as cross-country vehicles.

It is customary to operate cars, buses, trains, and some ACVs, on some form of roadbed or track. As a result, the vehicle is constrained to a path that allows little or no excursion from the desired path without resulting in some form of damage or injury. The image content, apart from the roadbed or track, is generally composed of buildings, other vehicles, the open country-side and vehicle signal lights. For cars, trucks and buses, the prime item of training is one of driver familiarization and vehicle control. It is generally assumed, perhaps incorrectly, that once the subject has mastered the trials and tribulations of controlling vehicles in congested city streets, he can also operate safely on the super-highway and the open road. As a result, training emphasis is on the congested city role of operations. Since the ETSS is intended to have a flexible capability, it should encompass both aspects of driver training.

It is anticipated that the future ACVs proposed for the land based transportation systems will be guided on some form of track. Therefore, to all intents and purposes they will have characteristics similar to those of trains. The visual requirements, therefore, have to allow for control of the vehicle on clear and free track as well as control of the vehicle during station arrival and departure. The image content for such a situation consists of the track ahead, the nearby trackbed, the surrounding scenic view, station buildings and vehicle signal lights.

With the exception of slightly different modes of operation, image content is essentially similar for vehicles riding a track and commercial wheeled vehicles. In both situations, the driver is seated in a compartment with a view to the front and to each side. A field of view of at least 120 horizontal degrees by 50 vertical degrees should be provided, since experimenter evidence indicates that judgment of speed and position is a function of peripheral vision and not entirely of the view immediately in front. It is also important for the subject to be able to respond to colored signaling devices.

The image content of the visual scene for vehicles of this group may contain some or all of the following elements:

1. Portion of vehicle in forward vision
2. The road or trackbed
3. Signal lights on stationary objects
4. Signal lights on moving objects
5. Local structures, buildings, etc.
6. Scenery on either side of the open road or track
7. Moving vehicles

Because of the constraints on the freedom of motion of this group of vehicles, the visual system might be of any of the following types:

1. Point light source
2. CCTV camera-model
3. VAMP (or motion picture film)
4. Digital electronic image generation

The choice of system would be based primarily on system flexibility, visual system performance, cost and reliability considerations. Characteristic performance parameters for this group of vehicles are as follows:

Longitudinal velocity	-10 to +200 mph
Lateral velocity	± 5 feet/second
Vertical velocity	± 5 feet/second
Visual range	30,000 feet
Roll	± 20 degrees
Pitch	± 5 degrees
Yaw	Continuous
Angular rates	70 deg/sec (yaw)
System resolution	2-8 minutes of arc

The class of cross-country vehicles comprises all vehicles primarily designed for cross-country applications, with exception of tanks and similar tracked vehicles. In general, this group of vehicles shares many of the visual requirements of track vehicles. The field of view requirement is the same, since the driver is seated in a cab with a windshield mounted in front and windows at the side. However, since the vehicle is designed to be operated in a cross-country environment, it is essential that the terrain be visibly reproduced and that terrain undulation be accounted for in the motion equations in order to simulate the cues that are critical in driving a cross-country vehicle. The problems in defining a visual system are similar to those for surface vessels experiencing wave action.

Three visual systems are theoretically acceptable for cross-country vehicles:

1. Motion picture (VAMP) system

2. Transparency reconstruction system

3. Digital electronic image generator

In each of these, it is necessary for the terrain information to be present if motion is to be considered. For the motion picture system the terrain information can be added as additional data on the sound track. For the transparency reconstruction system, the terrain information is already present as a density function on the elevation slide. For the digital electronic image generator, the terrain information is present in the form of a math model describing the terrain. Since the transparency system deteriorates at small elevations, only the motion picture and the digital electronic image generation systems remain in consideration for this application. A motion picture system has high image resolution compared with the digital electronic systems; however, the path is severely constrained by perspective distortion effects. The choice of system thus depends on the tradeoff of versatility versus high resolution.

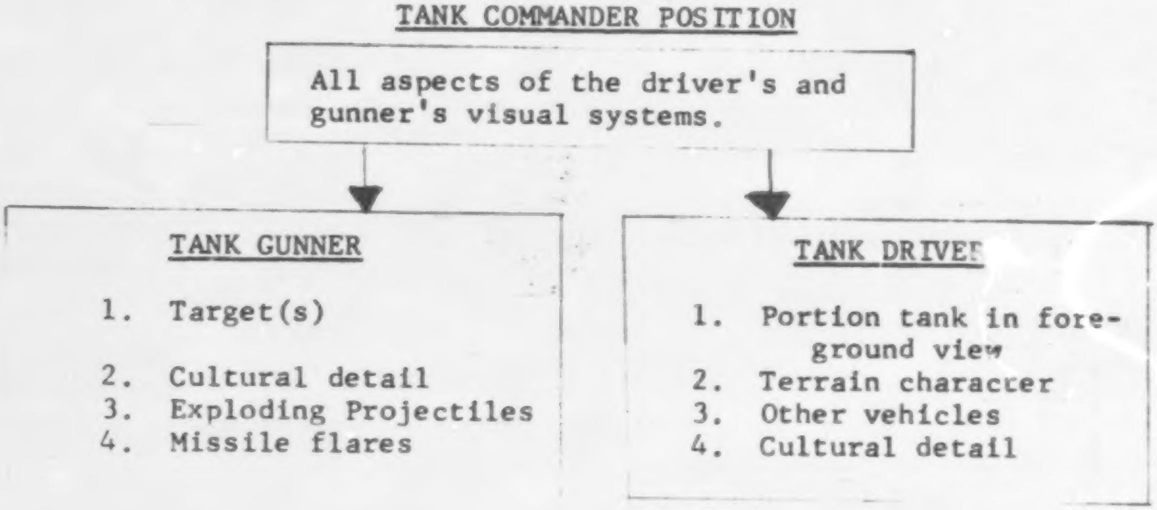
There are many factors that favor a color presentation rather than a black and white presentation for a simulator visual system. More intelligence may be derived from a colored scene, since color allows an increased scale of discrete chromatic values when compared to the black and white gray scale. (Spatial Data Systems uses a color transposition of black and white photographs for visual analysis.) Further discussion about the benefits of a color presentation may be found in Section IV.

Characteristic performance parameters for this group of vehicles are:

Longitudinal velocity	-10 to +60 mph
Lateral velocity	±70 feet/second
Vertical range	1,000 feet
Visual range	30,000 feet
Roll	±60 degrees
Pitch	±60 degrees
Yaw	Continuous
Angular rates	70 deg/sec (lg. turn)
System resolution	2-8 arc minutes
Field of View	120 x 50 degrees

Tanks and other tracked combat vehicles are essentially a combination of all the other vehicles plus certain special features. When a tank is "buttoned-up," the crewmen view the outside world through vision blocks, periscopes, or panoramic sights, which have restricted fields of view. The view in a typical tank through the vision blocks generally subtends a horizontal angle of 60 degrees and a vertical angle of 30 degrees. In the past, the majority of tank training has been done with hatches open and little training significance has been attached to the buttoned-up role of operation. However, the modern tank is designed for extensive operation in the NBC (nuclear-biological-chemical) environment; as a result, training emphasis will necessarily shift to the buttoned-up role. Therefore, the visual system should be designed primarily for the devices through which the crew observe the outside world.

Tank crew training involves training the driver and the gunner. Crews must also be trained to operate the systems at the tank commander's position. Each member of the crew requires a different aspect of the image content of the visual scene, as depicted by the following structure:



TANK COMMANDER POSITION

All aspects of the driver's and gunner's visual systems.

TANK GUNNER

1. Target(s)
2. Cultural detail
3. Exploding Projectiles
4. Missile flares

TANK DRIVER

1. Portion tank in foreground view
2. Terrain character
3. Other vehicles
4. Cultural detail

APPENDIX I

MOTION SIMULATION

Motion system cue philosophy is formulated, not only on what facets of motion information transfer the designer believes to be important, but also on the fact that in a vehicle simulator the motion base is constrained in terms of acceleration, velocity, attitude excursion and positional excursion capability. Thus, compromises in the design of specific systems must be made, based on the specific requirements imposed by the particular skill, skill level and training setting under consideration. These compromises require an experimental setting for the collection of relevant perceptual training and performance data.

Motion cues are associated with translation acceleration, rotational acceleration and attitude changes. It is believed, with reference to translational acceleration, that the onset phase of the vehicle acceleration profile contains the valuable portion of the information transfer associated with that particular acceleration profile. Relevant data are also contained in vehicle acceleration profiles of long duration, or sustained "g" maneuvers.

In simulating the onset phase of translational acceleration, the motion base is driven in a manner which, with the associated mechanical constraints, causes motion base acceleration onset to be in phase with vehicle acceleration. Where the vehicle acceleration profile exceeds system capability during this phase, appropriate "scaling down" is employed. At some point in time, either system velocity or positional excursion capabilities may be exceeded, due to onset phase simulation, causing cue termination to occur. Under extremely low-level cues this excursion may be an appreciable duration but short in comparison to many vehicle acceleration profiles.

In order to simulate these long-term accelerations it is necessary to "tilt" the subject, so that the earth's gravity induces a feeling of lateral acceleration. It is mandatory that the rotational acceleration level employed in such a "tilting" process imperceptible to the subject lest he confuse this motion with vehicle rotational acceleration. This application of motion base attitude change has been termed "gravity align" in that the apparent acceleration vector as computed at the trainee station, in a reference frame parallel to the vehicle body axis frame, is caused by motion base attitude reorientation to be coincident with the local gravity vector. The apparent acceleration vector is composed both of vehicle CG translational acceleration and the induced translational acceleration experienced at the trainee station due to vehicle rotations.

The translational acceleration cue simulation results, after cue termination, in a velocity level that must be reduced to zero (i.e., "washout") at subliminal acceleration levels. The resultant position excursion must also be returned to zero subliminally, since *a priori* knowledge of cue acceleration direction never exists and the most advantageous position for the motion base during quiescent periods is therefore at the center of the excursion sphere.

Rotational accelerations and attitude conditions are to be handled in a somewhat different manner. The reference attitude to which the motion base should return is considered as the gravity-align attitude. This tends to subordinate the gravity-align reorientation to that required by rotational acceleration and attitude simulation. This is indicative of the importance of rotational acceleration and attitude.

When the desired platform attitude excursions are small, the full value may be output; however, beyond a certain value there must be attenuation so that maximum vehicle attitudes, at least those desired for simulation, may be met within the mechanical constraints of the motion base.

The rotational acceleration onset cue is provided, in a one-to-one fashion, as the motion base begins to track vehicle attitude; likewise, the rotational deceleration cue is present as the motion base terminates the reorientation maneuver. Upon termination, the correct vehicle attitude, or a reduction thereof, is displayed to the subject. It is important to note that man's ability to establish attitude precisely becomes increasingly degraded as attitude increases in magnitude when referenced to the horizontal plane. Therefore, the attenuation of attitude maneuvers beyond the suggested ±110° should not jeopardize simulation. At the conclusion of the rotational maneuver, the residual gravity-align rate becomes effective and slowly causes the motion base to drive in that direction, which aids the sense of continuing translational acceleration. Because of this, the rotational acceleration and attitude scheme does not require, as is the case with translational acceleration simulation, a formal velocity and position washout scheme. In that gravity-align maneuvers do not require yaw capability, rotational acceleration simulation resulting in motion base yaw is following with a pseudo gravity-align rate which nulls the yaw displacement.

An additional facet of the motion cue scheme involves that period of time during translational velocity and position washout. Since cue simulation has been terminated due to the requirement of subliminally eliminating the resulting velocity and position excursion, it is not possible to accept an additional cue in this direction. However, in the course of either washout, an acceleration profile can be accepted which would aid the washout process. This type of cue would be termed a "reverse cue" and since motion may be oscillatory in nature, application of this principle provides a considerable increase of cue coverage.

Many vehicles have nearly unlimited excursion capability and large acceleration and velocity capabilities. In a vehicle simulator realistic motion cues are provided with a motion platform that has meager capabilities when compared to the actual vehicle. Therefore realistic cues must be supplied while utilizing a motion system that is reasonably sized.

It is important to bear in mind that the actual aircraft translational acceleration onset is to be duplicated. Because of velocity and excursion constraints the translational cue duration, although covering what is believed to be the most important phase of the acceleration profile, is of short duration. A second cue following shortly after the first and in the same direction cannot be simulated in the same manner as the first because of washout consideration. The latter limitation can be nullified to a certain extent, if necessary, by the inclusion of a translatory "jerk" simulation capability which would be available when washout is in progress. Such a contingency simulation, although less refined and somewhat inaccurate, would at least inform the subject of the presence of the second cue. This may be especially important when the second cue is the result of a pilot-initiated maneuver.

The gravity-align philosophy is limited to a certain extent since the rate of motion base movement due to gravity-align considerations must be maintained as subliminal. As a result, there exists a lag time between the onset and the duplication of the continuing acceleration. This limitation is not considered severe because an immediate exact duplication of the continuing acceleration magnitude may not be required by the average subject. It is mentioned as a limitation because of the fact that one-to-one acceleration correspondence is not available during this period and the absence of such a condition may be detected by some individuals.

Rotational accelerations are limited in only one aspect. As motion base attitude excursion increases from the normal horizontal position, increased attenuation in attitude reorientation occurs. Since the attenuation occurs in positional output, it follows that the resulting acceleration levels may be less, in this region, than an exact duplicate of the aircraft rotational acceleration.

During the period of cue simulation a number of demands are made of the motion system hardware. There are two basic types of motion base hardware configurations: fully cascaded systems and fully-synergistic systems. The former employs independent drivers or prime movers for each degree of freedom desired; to "stack" these prime movers, in order to possess more than one degree of freedom, is to cascade the prime movers. The latter employs one or more prime movers which affect more than one, or all, degrees of freedom desired. It is necessary to control all synergistic prime movers to obtain motion in any one degree of freedom. Various combinations of the above two extremes are used in current motion base hardware. Each of them has unique advantages and limitations. A cascaded system's capabilities are precisely known and easily-predicted at every point in time; however, the reserve or unused capability of a prime mover associated with one given degree of freedom cannot be employed in aiding the requirements, or demands, made on other prime mover associated with a different degree of freedom. Cascaded systems are generally fairly bulky and, more important, heavy systems requiring, in general, a larger energy source to equal the same capability as with the synergistic system. Cascaded systems are also subject to vibrational problems among the degrees of freedom.

Synergistic systems, although somewhat lighter and requiring smaller energy demands, also have definite limitations. Within a synergistic system, the capabilities of all prime movers may be devoted to causing motion in any given degree of freedom. This advantage is accompanied by limitations where a demand of one of the degrees of freedom compromises the capabilities previously available in any of the remaining degrees of freedom.

A wide variety of hardware implementations for motion system platforms exists. All implementations cause the motion platform to move as the result of actuator movement which is controlled by a motion cue math model program. All implementation may be encompassed by the cascaded and synergistic systems previously mentioned. The following paragraphs outline various possible motion platform configurations together with the drawbacks of each system.

Another type is a synergistic system utilizing both rotary and linear actuators to achieve the desired motion. This system used three rotary actuators with three linear actuators: each rotary actuator is supported by a linear actuator. The linear actuators are arranged on orthogonal axes when the system is at its equilibrium point. The system is represented by Figure 27 (Page I-6). This system has some design limitations, summarized below:

The system relies on rotary actuators to provide rotary motion. For a platform with a good rotational response the rotary actuators would be very large and heavy. Also the servo valves to control the rotary actuators are slow acting if the desired mass flow is achieved.

The mechanical design of the combined linear actuator and rotary actuator is an area beset with many problems. The rotary actuators have to support the thrust of the linear actuators, causing severe design problems in the rotary actuator. The rotary actuator and the hydraulic ram of the linear actuator would have to be mechanically coupled, so as to transmit rotary motion to the platform. In order to support the platform, the linear actuators would have to be of massive proportions, since a single actuator may be required to support the total mass of the system. Such a system is beyond the present state of the art.

Figure 28 (Page I-7) shows the general arrangement of a cascaded system. The simulation station is enclosed in a three-axis gimbal ring supported by a two-axis table which in turn is supported by a number of vertical actuators. This system has

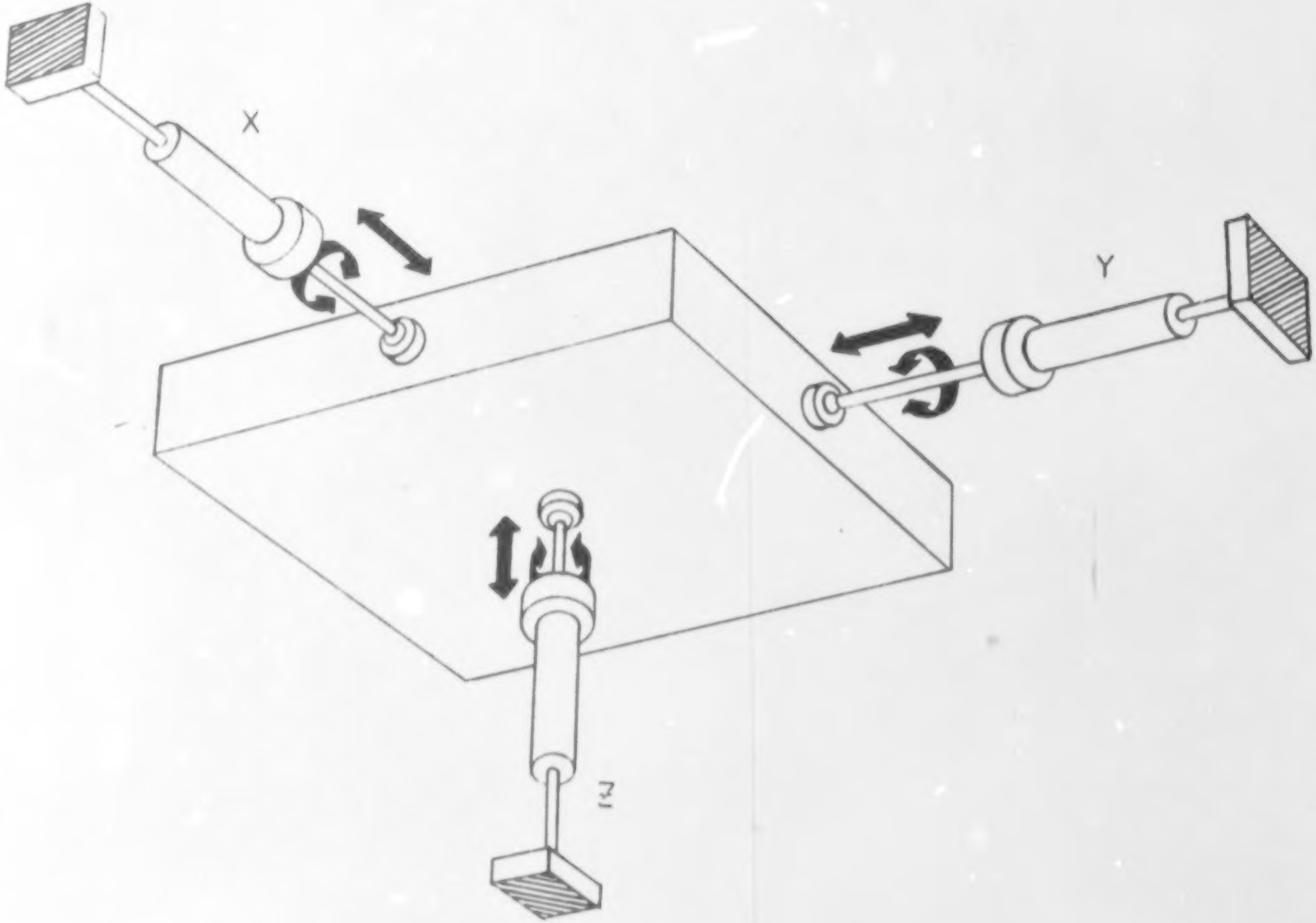


Figure 27. A Motion System Utilizing Combined Rotary and Linear Actuators

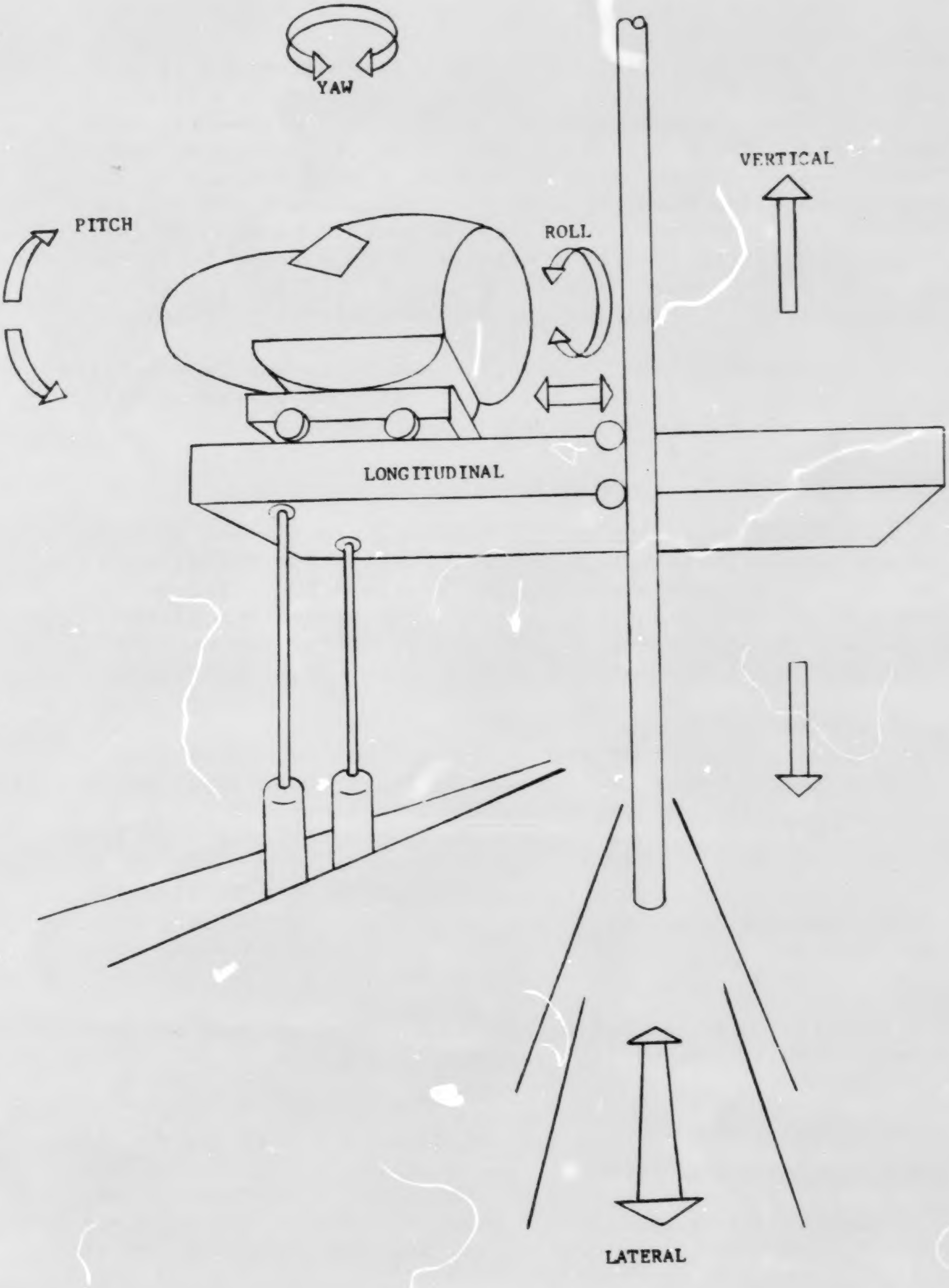

YAW
PITCH
ROLL
VERTICAL
LONGITUDINAL
LATERAL

Figure 28. A Cascaded Motion System Combining Linear and Rotary Actuators

the same failings in regard to the rotary actuators as the previous method if a good rotational response is desired. However, with the exception of the vertical actuators, only the lateral linear actuators have to be centered with the forces due to accelerating the moving mass. Because of the magnitude of the mass required to provide track-way for each lateral axis, however, the linear actuators have to be correspondingly larger if a good acceleration response is to be achieved. An example of a large system of this type is the NASA Ames Flight Simulator for Advanced Aircraft (FSAA).

A beam and gimbal suspension system is one in which the rotary motion is cascaded and the linear motion synergistic. Figure 29 (Page I-9) illustrates the general arrangement. This system suffers from a number of disadvantages, all involving mechanical design.

The system relies on rotary actuators for the three rotary axes. These actuators tend not to have sufficient capacity to produce a good rotary acceleration. Because of the cantilevered beam construction, the dimensions of the beam must be of massive proportions to resist any bending moments. The gimbal rings must also be of massive proportions to contain the simulation compartment. The total moment of the beam and simulation compartment is withstood by the two linear actuators A_1 and A_2. Consequently, these must be of very large dimensions to have a good translational performance. Difficulties may result in this system due to beam resonance, which may be compounded by the variable beam length.

Translation, which is synergistic is done by pivoting or slewing the beam, extending or contracting the length of the beam and compensating the beam angle with an equal rotational angle.

This system is feasible for small compartment weights, but is totally impractical for compartments of 20,000 pounds or over.

A synergistic six-degree-of-freedom motion system utilizing six linear actuators is illustrated in Figure 30 (Page I-10). The platform bearing the simulated compartment, crew, and visual system hardware is supported and driven in translation and attitude maneuvers by varying the length of the six-hydraulic rams which support the platform. Each ram is so positioned and gimballed at its platform and floor attachment

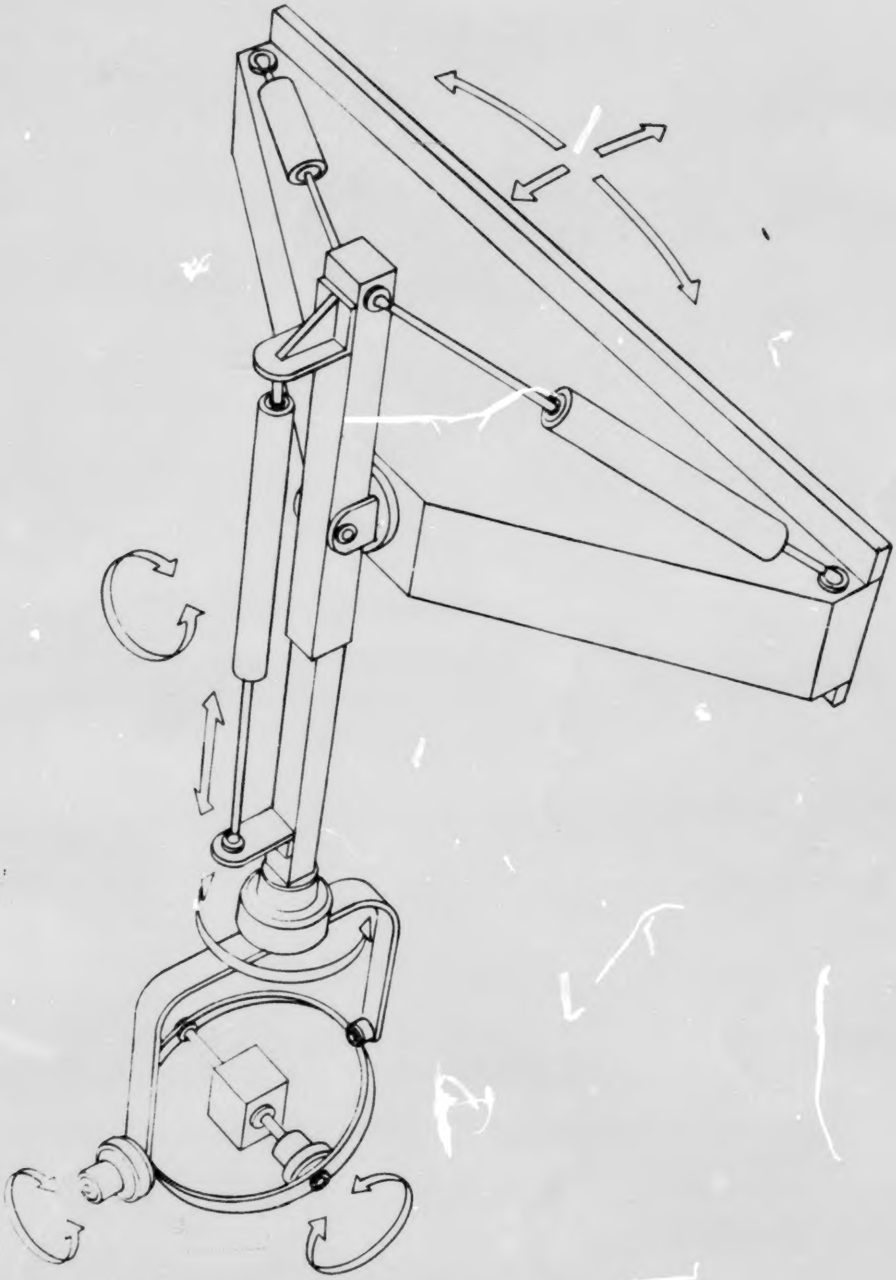


Figure 29. Beam and Gimbal Motion System

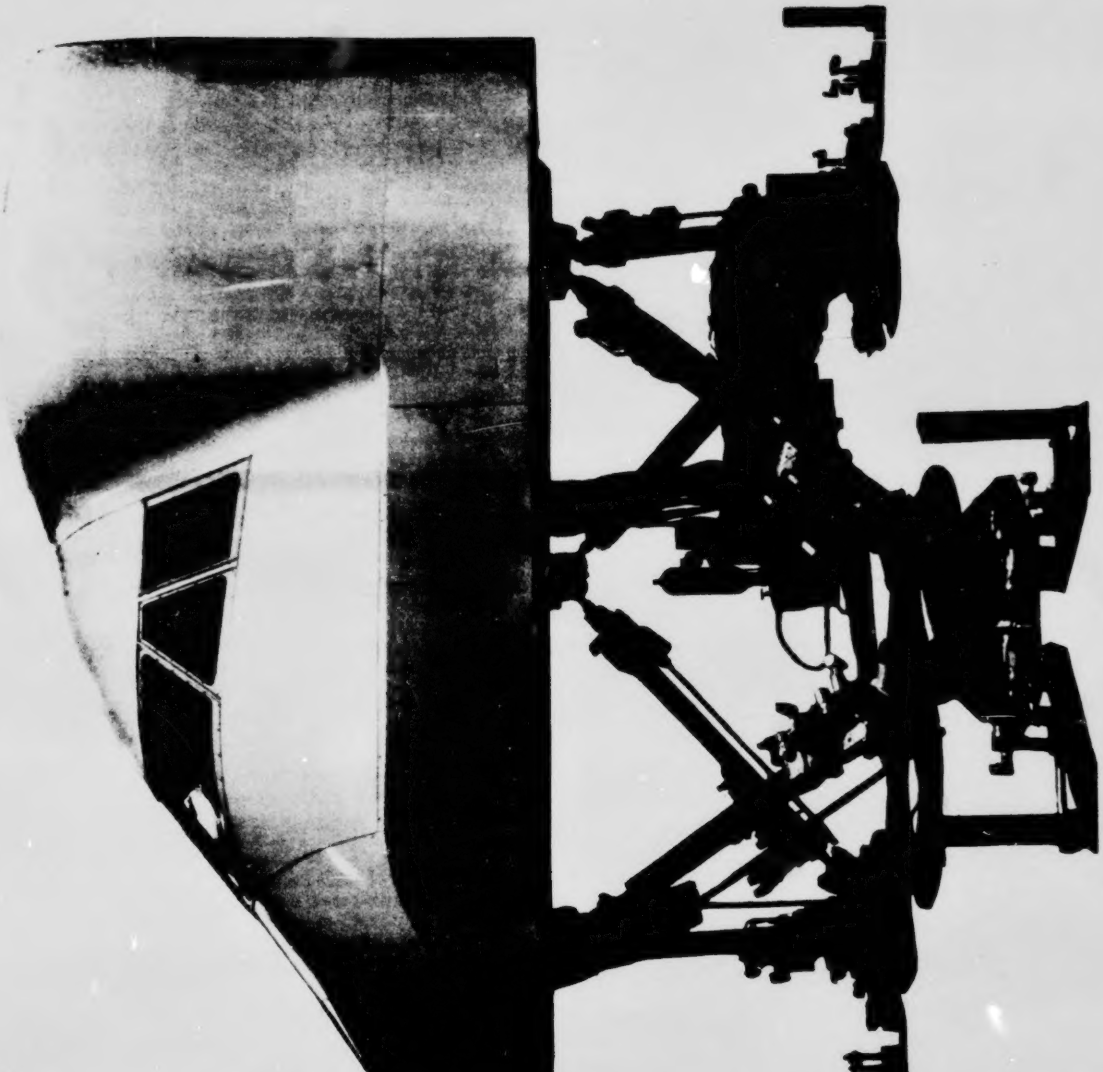


Figure 30. Typical Synergistic Six Degree-of-Freedom Motion System

point that within the normal operating limits and ram attitudes no constraints exist in extending or shortening the length of a ram. Changing the length of a ram results in a translation and attitude change of the supported platform. Such platform changes always occur, but the nature of the change is not easily predicted. Conversely, to provide a known translation and attitude change, all six rams must be taken together and the exact ram length, as a function of time, must be predicted.

The linear-actuator motion system possesses a number of advantages over the other systems described. The most notable one is that no rotary actuators are used and hence the rotational accelerations may be considerably higher. Since all six actuators support the platform and cause all attitude and translation excursions, the actuators may be smaller than those in some cascaded systems. The system shown was built by Link Division of the Singer Company for use in Boeing 747 and Lockheed L-1011 aircraft simulators.

All of the foregoing motion systems have a six-degree-of-freedom capability. For special requirements, one or more degrees of freedom may be eliminated by changing the hardware, or by changing the math model of the motion system cue program. There are many other types of motion systems not mentioned which use combinations of linear and rotary actuators.

The problem of synchronizing the motion and visual systems with the rest of the vehicle systems is an important one, if high-fidelity simulation is to be achieved. Unfortunately, in digital simulation there is always some lag which is due simply to the fact that computations are done sequentially.

Since lag is unavoidable, it must be minimized through proper sequencing of programs within a computation frame. If the programs are executed at a rate of 20 times per second, the worst-case lag time due to computation sequence can be kept to 0.05 seconds.

An additional problem is due to the fact that usually both the visual and motion systems use position servos to drive their respective systems. In the motion system drive signal formulation, vehicle accelerations can be taken from the equations of motion of the vehicle and integrated twice, within the same frame in the motion program, to obtain position outputs for the servos. This is a valid approach since the motion system is attempting to give acceleration cues. The visual system is somewhat different, however, because it provides position cues. A solution to this problem is to use a closed-form integration technique within the dynamic equations program for the second integration (velocity to position) and output this position to the visual system.

A method which can be used to further eliminate any lags between visual system, motion system, and vehicle instruments is to synchronize all output signals to these systems when the required computations have been completed by outputting these signals as closely together as possible.

In vehicle simulators which have the transfer function of the actual vehicle control system simulated, it may be possible to generate a lead which partially compensates the computational lag by eliminating some or all of the lag due to vehicle system transfer function simulation.

Another cause of delay in the response of the visual and motion systems is the response of the servos used to drive these systems. It is possible to reduce this lag by either hardware or software methods. The hardware method is to include an electronic servo transfer function. This is readily accomplished for the visual system and for a "cascaded" motion system. For a "synergistic" motion system, however, this is not such a straightforward matter, requiring the use of a software lead function throughout. The manner of implementing a software lead function is to multiply the drive signal by the digital approximation of the reciprocal of the servo transfer function. The constants in this expression can be adjusted so that synchronization of the visual and motion systems is assured.

The motion system may become unsynchronized when the mechanical limitations of the system are approached. If the motion system becomes unsynchronized because of an abnormal duty cycle, diminished cues or no cues at all should be given, rather than false cues. This can be achieved by feeding the actual position back to the computer and comparing it with the commanded position. If the difference exceeds a given limit, the drive signal program can constrain its commands until the position servos catch up.

System time lags can be predicted and identified most accurately during the design phase, and the methods discussed above implemented to minimize and synchronize these lags.

The motion cue math model, as described, is completely general. It is set up to compute motion at the vehicle controller's station. The vehicle controller's station generates the desired motion cues consonant with the desired motion cue principles and generates the commands to the motion system hydraulic servos. Once the drive signal model is set up for a particular motion platform, it can handle motion cues for any vehicle. The only changes in the model from vehicle to vehicle are the constants which define the position of the control station with respect to the particular vehicle's center of gravity, and the gain constants which accentuate or de-emphasize the importance of motion cues among the six degree of freedom. The drive signal math model is then adaptable to any vehicle by changing a few constants. Changes may also be made easily to accommodate subjective opinion by changing the gain constants which control magnitude and duration of onset cues, as well as acceleration levels associated with velocity washout and positional "sneakback."

APPENDIX J

VISUAL SIMULATION

Image generation consists of producing organized visual data from the system's data source. A natural means of generating visual data is to use a model structure that faithfully duplicates the informational content of a real world scene, and viewing this model with a TV camera that is servo-controlled to duplicate the motions of the simulated vehicle. The most serious technical disadvantage of the camera-model approach is the achievable depth of focus on the TV imaging lenses. In practice, it has been found impossible to maintain adequate focus from the operator's near field to the horizon during operations occurring near the surface.

Recent development by NTDC has resulted in a pin-hole TV camera, using a low light level camera tube, which has an extremely good depth of field.

Since the advent of visual simulation great effort has gone into the development of point-light-source transparency systems. They are in theory capable of simulating the view from an operator station of at least a two-dimensional ground terrain in correct perspective without the use of sophisticated electronic equipment.

Basically, this technique uses a point light source of high brightness which casts the "shadow" of a photographic transparency onto a screen in front of the operator. The transparency is mounted on a servo-driven gimbal system which rotates and translates to portray the motion of the simulated vehicle. The transparency is an orthophotograph of the terrain over which the simulated vehicle maneuvers. The relative position of point light source and transparency is analogous to the position of the actual vehicle with respect to the ground.

The quality of the final projected image depends on several factors. The resolution of the shadow of the transparency on the projection screen is a function of the photographic resolution of the transparency, the distance between light source and transparency (magnification), and the dimensions of the light source. The final image brightness is a function of the projection distance and the total radiant energy output of the light source. The major drawbacks of point source systems have been low resolution (due to the finite size of the light source), limited range of simulated altitude (the minimum distance which is physically possible between light source and transparency), and the low brightness of the displayed image.

During the last few years, however, technology has progressed in many areas pertinent to point-light-source simulation. Laser light sources are available today that are focusable to an extremely small spot with a brightness orders of magnitude higher than that of conventional light sources. White laser light could be generated by combining three individual lasers of different wavelength. The relatively small diameter (1-3mm) of commercially available CW lasers permits the use of extremely small optical elements to form the necessary image of the light source so that the eye point may be brought physically very close to the transparency.

The difficulty of establishing the correct viewing geometry so that correct angular relationship (and thus perspective) is obtained between the image-generating light cone and the viewing field may possibly be solved by optical techniques. The use of some quasi-spherical wraparound screen or virtual-image systems using aspheric concave surfaces of revolution may be possible.

Unfortunately, quantitative analysis of these possibilities shows that the implementation of an advanced type of point source system is still impractical. In spite of the high brightness of laser light, the achievable brightness of the displayed image will still not meet today's requirements. The power output of present commercially available (and practical, usable) CW lasers is in the milliwatt range. Even with the most efficient display optics, using high-reflectance screens, the resulting picture will be very dim for any reasonable angular field of view. Finally, point-light-source transparency systems for visual simulation are still characterized by limited area coverage, insufficient resolution and low image brightness.

Photography offers the most compact and efficient means available for the storage of visual data. Systems are being constructed in which terrain information, covering areas greater than 200 x 200 miles, is presented on photographic plates no more than 20 inches square. The basic system concept consists of scanning the information contained on the plates with a scanning system which converts the photographic data into a TV image.

The basic problem encountered in the construction of such systems is the relatively poor resolution obtained at large scale factors. This problem cannot be solved simply by reducing the scale factor in existing systems, since the result would be an unnaturally small visibility limit due to the restricted scan formats covered by the scanning optics employed. By designing a scan system that employs a small scale factor but variable optics to extend the size of the scan format, the scan transparency approach can be extended to achieve relatively wide area coverage at reasonable resolution levels. When such a technique is extended to include the three-dimensional effects of elevation information, by scanning a second plate synchronously with the prime-terrain storage plate, a system with an attractive combination of wide flexibility and reasonable resolution results. At the present level of technological development, no three-dimensional scan transparency has been built that provides an acceptable picture.

The basic characteristics of scan transparency systems are that they provide maximum information content and economy of information storage, but are limited in their ability to generate the ultimate in resolution when measured against motion-picture image quality.

A motion picture image of an actual simulated maneuver recorded on high-resolution 70 mm color film is capable of producing the ultimate in presentation quality. The problems of dynamic range encountered in other mediums, which must be scaled to describe the entire simulated world even though only a small portion of this world is visible at any time, vanish in a motion picture system, which uses all the resolution capabilities of high-quality film to store one frame of displayed information at a time. The large dynamic range of the projected scene is accommodated by the partially programmed passage of film through the projector.

The disadvantage of such a scheme is that it is at least, partially preprogrammed. It is important to note, however, that for critical maneuvers there are rather precise limits on excursions which can be made within a prescribed envelope without jeopardizing the safety of the filming vehicle. This is true not only of the normal maneuvers but also for those which must be made in the event of emergency conditions. If the pilot fails to stay within this envelope of safe maneuvering the mission will necessarily be ended. What is suggested, then, is a means by which highly detailed and accurate photographic information is made continuously available to the simulation display system in accordance with the vehicle's instantaneous position and attitude. If this information can be correctly presented for any point within the permissible envelope, then it becomes possible to achieve the unmatched realism of motion picture presentation, while still accommodating excursions due to maneuvering the vehicle within the prescribed boundaries.

Various image projection systems are used to project the generated image onto a suitable viewing surface. Television projection systems create a high-intensity image on the face of a relatively small cathode ray tube and then enlarge this image optically on a screen. The basic design problem encountered is achieving adequate brightness and resolution. In the imaging process, light is lost for two reasons: first, the optical system required for imaging cannot possibly pick up all of the energy radiated from the face of the cathode ray tube since it radiates in all directions, and a fixed separation is required between the tube and the optical systems; second, since the area of the screen is many times larger than the area of the cathode ray tube, the energy picked up by the optical system must be spread over this relatively large area, with a resultant loss in screen brightness proportional to the ratio between the two areas or to the square of the magnification of the system.

The TV system is capable of being extended to simultaneous color projection by operating three systems and optically adding the three primary colors at the screen. The extension of high-brightness TV projection to color, greatly increases the cost and complexity of the system and the problem of registration among the three color images.[1]

Film projection systems do not suffer from the problem of color registration or from the problem of resolution loss with increased brightness. Color fidelity and registration are inherent in the color film employed, and higher brightness is simply obtained by increasing the intensity of the light source.

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[1] A single channel color system such as the G. E. Light Valve, where mixing is within the projection tube, is considerably lower in cost than the three system approach.

Because of these advantages, the problem of covering large angular fields of view is simplified. With a film projection system it is easy to achieve a brightness well in excess of 10 foot-lamberts, and operation at this brightness level imposes no reliability or maintenance problems.

The subjective resolution obtainable by film projection is well known from experience in the entertainment industry. Calculations indicate that this resolution is limited by film characteristics. With the best available motion picture equipment, taking into account the influence of cameras, copying equipment, etc., the final system resolution of 70 mm color film is about 22 line pairs/mm at a contrast ratio of 1.6:1 and 90 line pairs/mm at a contrast ratio of 1000:1. A typical VAMP film can resolve about 35-40 line pairs/mm.

A further advantage in the use of film projectors, if they can accept a standard motion picture format, is that several decades of operational experience have been accumulated on this type of equipment. This experience has mainly been in environments requiring a minimum of unscheduled downtime and maintenance practices suitable for moderately skilled personnel working on site. As a result, design principles are well known and the mechanisms have been refined to an extremely high level of reliability.

Visual displays in some early simulators made use of either television monitors or rear-projection screens mounted in the vehicle windows. These are unsatisfactory and have been outmoded because of large parallax errors introduced by head motion and the psychological sense of unreality caused by eye convergence and accommodation for an image located so close to the observer. Present-day systems use either virtual images (with either refractive or reflective optics) or large theater-type screens located a considerable distance from the trainee.

A basic refractive infinity-image system (or virtual-image system) consists simply of a large plano-convex viewing lens mounted outside the simulated cockpit or replacing the windows, and a front or rear-projection screen located, in theory, at its focal plane. Any image projected onto the screen and viewed through the "eyepiece" is thus seen at infinity. Over a limited field of view, this approach provides reasonably good image quality.

Viewing lenses have been built up to 36 inches in diameter, providing a field of view of as much as 60 degrees. For practical reasons, these lenses are made of acrylic plastic, and their refractive power is limited by the fact that the optical plastic is commercially available only in thicknesses up to four inches. However, eyepieces have been built using several plano-convex lenses in tandem in order to increase lens power and reduce the F number. Relative apertures as low as F/1 have been suggested. This permits the design of a more compact system with smaller screens and consequently brighter images. Unfortunately, as the F number gets smaller and the lens power increases, the optical quality of the simulated scene decreases, and distortion, color aberrations at the periphery of the field, spherical aberration, and field curvature become quite noticeable.

Aspheric plano-convex viewing lenses with elliptical surfaces have been built which substantially reduce the problem of field curvature and produce a flat field for an observer located on-axis. Aspherical lens elements are generally made from optical glass, however, and large elements become very expensive.

By employing correction techniques in the image-forming or image projection systems, both the color and distortion errors can be adequately reduced, as long as extremely low F numbers are avoided.

Reflective eyepieces for infinity-image displays have been built with excellent optical quality. One version of a catoptric virtual-image system consists of a spherical mirror with the observer located at its center of curvature. Any object located at the spherical focal surface of the mirror is seen at infinity. This can be physically realized by introducing a beamsplitter at 45 degrees to the center axis between mirror and observer and locating a spherical projection screen outside the direct field of view. Since the projection screen is viewed through the beamsplitter twice, the transmission of the system is at best 20%. Systems of this type are limited in vertical field of view by the problem of interference between the line of sight to the spherical mirror and the required input surface. This objection can be overcome if one limits the display window's vertical field of view, or if one employs a second beamsplitter and spherical mirror to generate an aerial image at the focal surface of the viewing mirror rather than employ a screen or CRT.

More recently, a configuration for a reflective display system has been developed which uses polarized beamsplitters in an arrangement that compresses the display components into approximately the size that would be required for a refractive system. Like the refractive system, this technique requires the use of rear-projection screens to provide an object surface for the display. The limits on angular field are uncertain at the present time because of the effect of varying angles of incidence on the efficiency of polarizing beamsplitters which direct light through the system. In principle, however, the concept offers the possibility of eliminating many of the aberrations associated with refractive elements, while at the same time creating large fields of view with relatively small optical elements.

The major disadvantage of both the dual-beamsplitter spherical mirror approach and the more compact polarizing approach is their low light efficiency (both systems have in the order of 4% transmission).

No visual system to date has achieved the ideal objective of providing a simulator with an external visual environment that is indistinguishable from the real world. Indeed, the qualities demanded of a visual system by the human eye and the human brain are far in excess of the current state-of-the-art capabilities in visual simulation.

APPENDIX K

SOUND SIMULATION

The complexity and the variety of sounds experienced in connection with the multitude of systems within the cognizance of the ETSS make it essential to define the characteristics of the human ear and body in hearing and feeling sounds. Figure 31 (Page K-2) represents thresholds of hearing and feeling plotted against frequency. It should be noted that the threshold of feeling is approximately constant at 120 decibels (20 N/m^2), which is considerably above the normal sounds heard by the ear. The frequency range for hearing is from about 60 Hz to 18 kHz, with maximum sensitivity occurring at 2 kHz. to 3 kHz.

A multitude of objects emit sonic energy. Some of this energy is capable of being recognized by select groups of species, while other groups recognize other portions of this energy. The ETSS will concern itself only with the synthesis of sound or feeling within the spectrum of human comprehension. In the types of experiment to be performed, sound may either reinforce or indicate a specific cue, or act as a distracting medium that serves to mask the cue from the subject's attention.

Sound effects may be generated using three techniques:

a. The actual sound emitter which it cues at the appropriate moment.

b. Recordings on disc or tape of the desired sound emitter cued at the appropriate moment.

c. A sound synthesis system peripheral to the computer complex.

The use of the actual sound emitter is frequently not the best method of obtaining desired sound, since the emitter must be interfaced to the equipment used for the experiment; this may be an easy or a difficult task, depending on the emitter. The cueing of the emitter is dependent on how the device is interfaced to the experiment. Also, the use of the actual sound emitter may be precluded by size or safety requirements. For example, the sound of an automobile horn may be generated by using the actual device wired to a computer-controlled relay, but the sound of an aircraft breaking

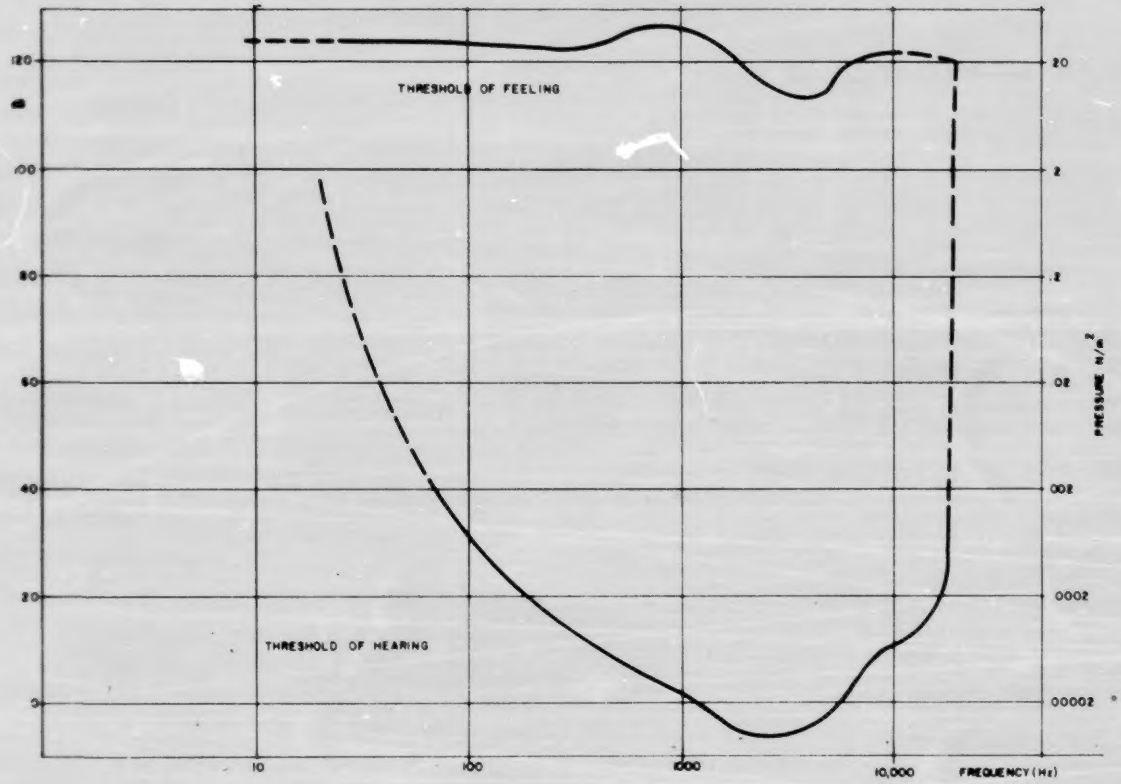

Figure 31. Feeling and Hearing Thresholds Versus Frequency

the "sound barrier" at low level must be generated by sound recordings or synthesis techniques, thereby eliminating the inherent dangers of such a maneuver to the personnel performing the experiment.

Assuming that sufficient acoustic power may be generated by the amplifier and acoustic transducer driven by the tape recorder, sound recordings satisfy most of the requirements of the audio system. However, tape recordings suffer from delayed access to a particular recording. In contrast, disc systems may reduce the access time at the penalty of reduced recording time. Provided that a suitably powered acoustic transducer is available, a record/playback system allows an almost unlimited library of sounds to catalogued at the expense of access or recording time.

The development of a system for sound synthesis consists of two equally important phases: establishment of the parameters and characteristics of the sound to be synthesized, and development of the techniques of generating the desired sounds. A sound synthesis system suitably interfaced to a computer allows an almost unlimited library of sounds to be generated with an imperceptibly small access time.

Since the sounds to be generated are those that pertain to the range of hearing of human subjects, it is important to establish the characteristics or signatures of the sounds that are anticipated to be of interest in ETSS experiments. Other sections have discussed the visual and motion aspects of vehicles operating in the earth, sea and sky environment; the following discussion applies to sound signatures applicable to a human subject operating in this environment. Table 23 (Page K-4) provides a short summary of sounds that have been synthesized. This list is by no means complete; the variety of sounds that may be generated is limited by the problems of sound analysis and implementation. A very important feature to be considered in the physical location of the sound source is the possibility of locating relatively low-power amplifiers and loudspeakers at strategic points corresponding to the emanation point in the actual vehicle. Much of the sound synthesis problem is affected by subjective considerations; thus absolute fidelity is not as important as providing flexibility to allow suitable interfacing with the other environmental factors of the simulated system.

TABLE 23.

SOUND CHARACTERISTICS

Basic Aircraft Sounds

- Jet Engine
- Turbo Prop Engine
- Reciprocating Engine
- Auxiliary Systems
- Air Hiss
- Ventilation Systems
- Tire Screech
- Weapon Noises
- Crash Effects

Undersea Sounds

- Propeller Beats & Screw Count
- Sonic Sensor Returns
- Marine Biological Life
- Target Signatures
- Weapon Noises
- Doppler Shifts
- Ship Activity (Onboard)

Engine Sound Synthesis Requirements for Gas Turbine

Frequency - Function of RPM

Amplitude - Function of RPM and Thrust

Components - Turbine Whine, Compressor Whine & Jet Exhaust

Frequency Range - Turbine--
80 Hz to 12 kHz
Compressor--200 Hz to 8 kHz
Jet Exhause--10 Hz to 600Hz

Diesel Train Sounds

- Exploding Torpedo
- Malfunction Bell
- Warning Whistle
- Engine Bell
- Sander
- Air & Brake Hiss
- Engine Whine
- Brake Noise
- Rail Click & Rumble

APPENDIX L

CUSTOM DESIGN STUDIES

1. CUSTOM HARDWARE DESIGN STUDIES

Investigations into hardware necessary to fulfill the functional requirements of the ETSS led to studies aimed at multiple use of as many items of ETSS hardware as possible.

There were two reasons for this:

a. Since the ETSS will generally be used in one experiment at a time, multipurpose devices will provide attractive cost benefits.

b. The more functions a given device can perform, the fewer instances there will be of equipment standing idle when the facility is in operation.

One problem area is the subject station configuration. Two studies were performed in this area: one concerned with the arrangement of display and control hardware on flexible panels; the other with the use of TV insetting techniques.

Another study was performed to enable a specification of the universal terminal to be determined. The universal terminal acts as the interface between one or more researchers, the computing system, and the experiments being performed.

Also subject to an analysis was the problem area surrounding the derivation of a universal math model defining the equations of motion of any rigid body supported in any medium. The findings are presented later in this appendix.

The last study in this appendix is concerned with the audio-visual capability of the ETSS. A possible design that combines all the audio-visual features required for the ETSS into one device is presented.

1.1 MULTI-PURPOSE EQUIPMENT PATCH PANEL. This study was aimed at providing a method of building various panels containing representations of all types of controls and displays. The ETSS inventory would contain various types of standard, off-the-shelf controls and displays, the only requirement being that each item be compatible with the outputs of the patch board. The panel would be constructed with the hardware required to connect it with the appropriate jacks in the patch board. Wiring on the adapter can be color-coded to allow for quick, easy recognition of terminal inputs (e.g., red for digital inputs, blue for digital outputs, black for ground wire, yellow for analog inputs, green for analog outputs).

To account for experiments that might be performed with a unique instrument such as an attitude direction indicator (ADI), specialized instrument drives will be required. Although the driving mechanism will be an integral part of the actual instrument, such as found in aircraft simulators, its function must be described in terms of driving forces and must accurately simulate, within a given tolerance, actual operations.

Acting mainly as an interface between panel mockup instrumentation, special physiological experiments and the computer complex, the patch board will allow for complete flexibility of experimentation with either different and varying panel configurations or discrete electrical components. This feature, plus the capability of "quick change" for instrumentation, will provide the experimenter with speed and ease of implementation.

Investigation of patchboard design requirements for existing simulators dictated the need for capabilities shown in the following tabulation:

COMPUTER INPUT/OUTPUT	NO. & TYPE OF RECEPTACLES	SIGNAL
Analog to Digital	32 min. bayonet.	Analog signal Analog return System ground (screen)
Digital to Analog	32 min. bayonet.	Analog Signal Analog return System ground (screen)
Digital Inputs	32 min. bayonet.	Digital signal Digital return System ground (screen)

COMPUTER INPUT/OUTPUT	NO. & TYPE OF RECEPTACLES	SIGNAL
Digital Outputs	32 min. bayonet.	Digital signal Digital return System ground (screen)

Using these specifications for patchboard design establishes the maximum number of instruments to be utilized by the experimenter. If the experiment or exercise calls for more than is provided by one patchboard, two can be utilized to accommodate the increased instrumentation. Mobility in this particular case, would be justified for the patchboard hardware. Interconnection between the patchboard and the linkage system should be such that, in the case of increased activity (experimentation), connecting added hardware would in no way hinder operational standards.

An examination of existing requirements for the system was analyzed to justify the use of 32 receptacles for the A/D's, D/A's, DO's and DI's. For a high-density experiment, the number of instruments that could be used ranges from approximately 10 to an undefined maximum. The number 32 was chosen because of its representative and inherent association to the 32-channel multiplexer associated with the system. To accommodate all computer inputs and outputs will require 128 miniature bayonet receptacles. These receptacles will be color-coded to ease implementation with the color-coded wiring.

The system just described works well for simple instrumentation such as switches, meters, digital readouts, etc. However, to maintain an inventory of complex instrumentation (navigation displays, for example) would be impractical because of the cost and the inherent inflexibility of that type of device. (See Figure 32, Page L-4).

1.2 Multi-Purpose Compartment. This study is concerned with a flexible method for generating a medium-fidelity representation of the subject's operating compartment using television production techniques. Basically, the method uses special effects to combine a number of television video sources to form a composite picture. The composite picture can then be back-projected on a suitable screen to achieve realization of the correct proportions and size of the display. The combination of individual picture elements into a general background scene may require three video sources: (See Figure 33, Page L-5).

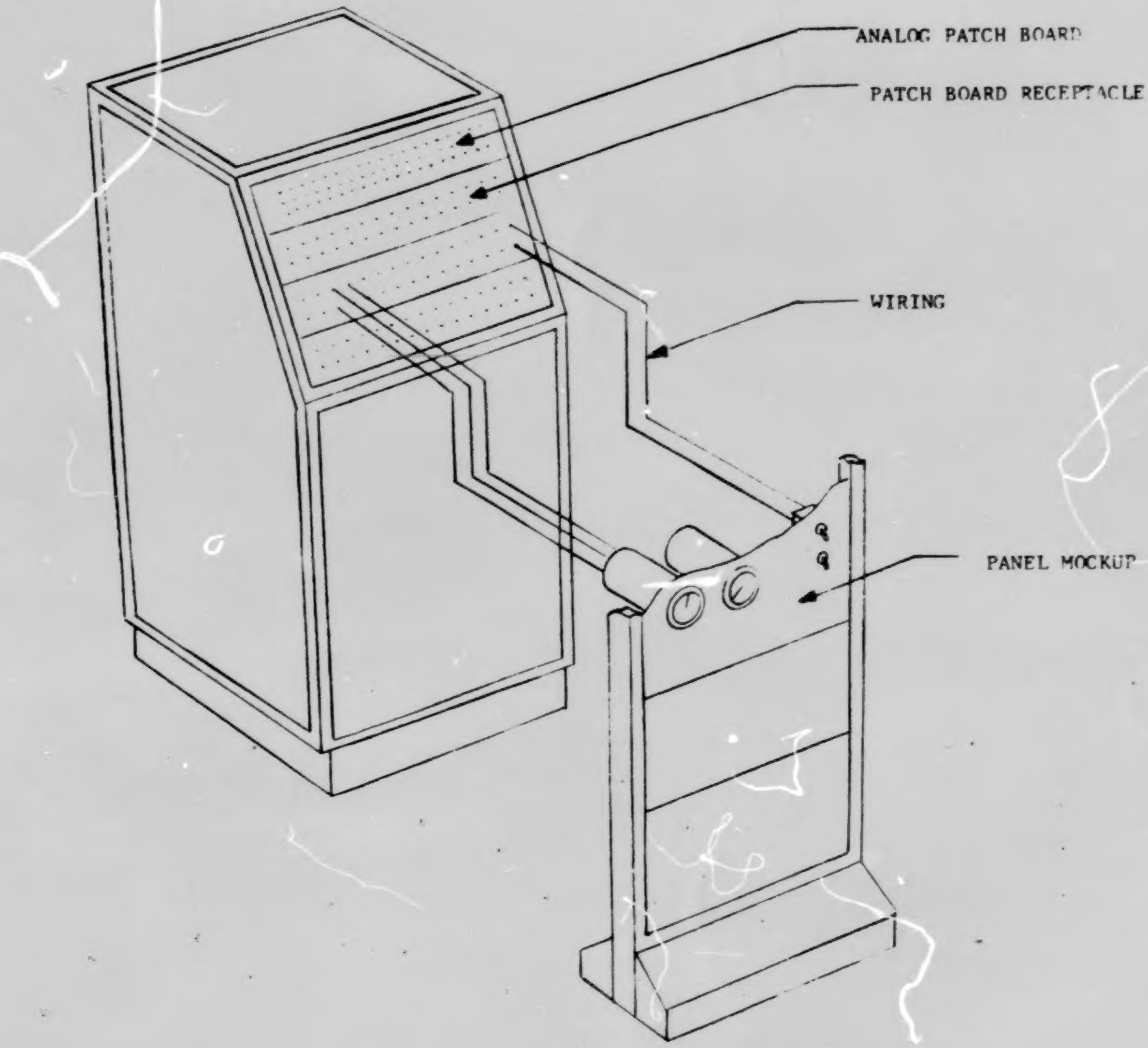
ANALOG PATCH BOARD
PATCH BOARD RECEPTACLE
WIRING
PANEL MOCKUP

Figure 32. Multi-Purpose Patch Panel Sketch

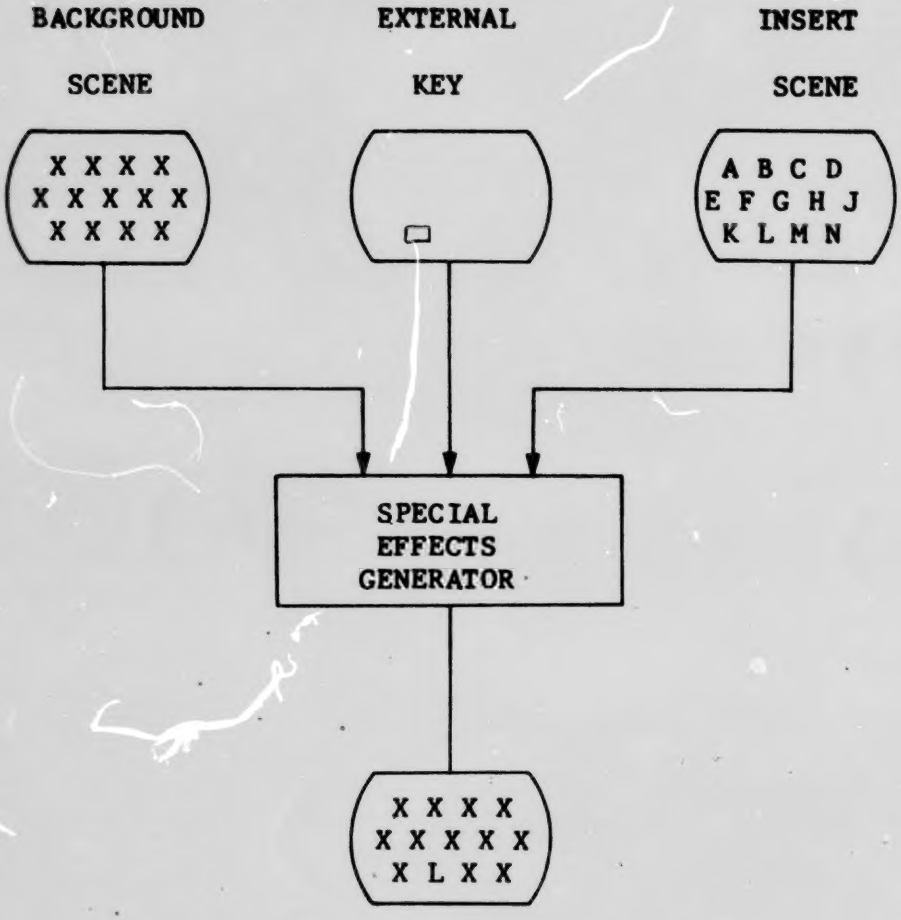
BACKGROUND SCENE
X X X X
X X X X X
X X X X
EXTERNAL KEY
INSERT SCENE
A B C D
E F G H J
K L M N
SPECIAL EFFECTS GENERATOR
X X X X
X X X X X
X L X X

Figure 33. Video Composition Schematic

a. Background video

b. Black and white external key video

c. Inset video

In practice, the special effects generator transmits the background scene for any white signal from the external key video. For any black signal from the external key, the inset video is transmitted.

The position of the external key in relation to the confines of the TV frame determines the position of the insetted video. Since the three video sources are in synchronism with each other, the subject matter for the inset video which is in the same relative position as the external key will be insetted into the composite picture in that same relative position.

This is the basic concept used in the generation of a medium-fidelity representation of the training situation. The actual method would use a number of special effects generators, external key video sources, inset scene video sources and a background scene video source.

Since this is a medium-fidelity representation of the training situation, the disposition of controls need not be realistic to the point of being in the correct position. The composite video representing the instrument panel and dynamic instruments is back-projected onto a screen in front of the subject. A typical complex for an experimental station is shown in Figure 34 (Page L-7).

An experimental station of this type could be used for many different applications, each application requiring a minimum of hardware change. Since the prime role of this device is to portray the interior features of an operational device, the main inset features (dynamic) will consist of instrumentation and the external visual scene. Typical applications of this device are:

a. Aircraft cockpit simulator

b. Land vehicle simulator

c. Surface ship system simulator

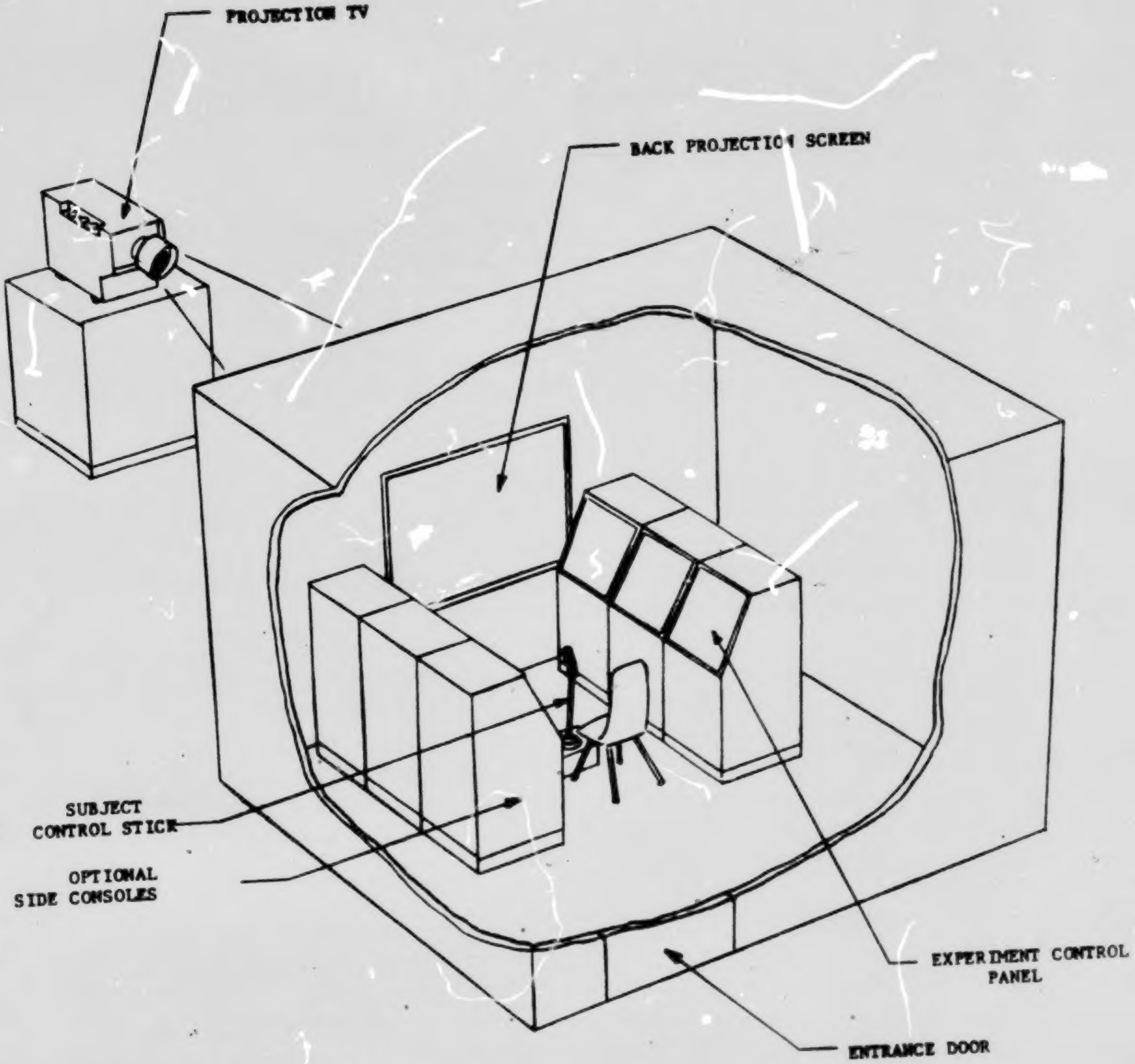
PROJECTION TV
BACK PROJECTION SCREEN
SUBJECT CONTROL STICK
OPTIONAL SIDE CONSOLES
EXPERIMENT CONTROL PANEL
ENTRANCE DOOR

Figure 34. Typical Back-Projected Display Configuration

a. Background video

b. Black and white external key video

c. Inset video

In practice, the special effects generator transmits the background scene for any white signal from the external key video. For any black signal from the external key, the inset video is transmitted.

The position of the external key in relation to the confines of the TV frame determines the position of the insetted video. Since the three video sources are in synchronism with each other, the subject matter for the inset video which is in the same relative position as the external key will be insetted into the composite picture in that same relative position.

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a. Aircraft cockpit simulator

b. Land vehicle simulator

c. Surface ship system simulator

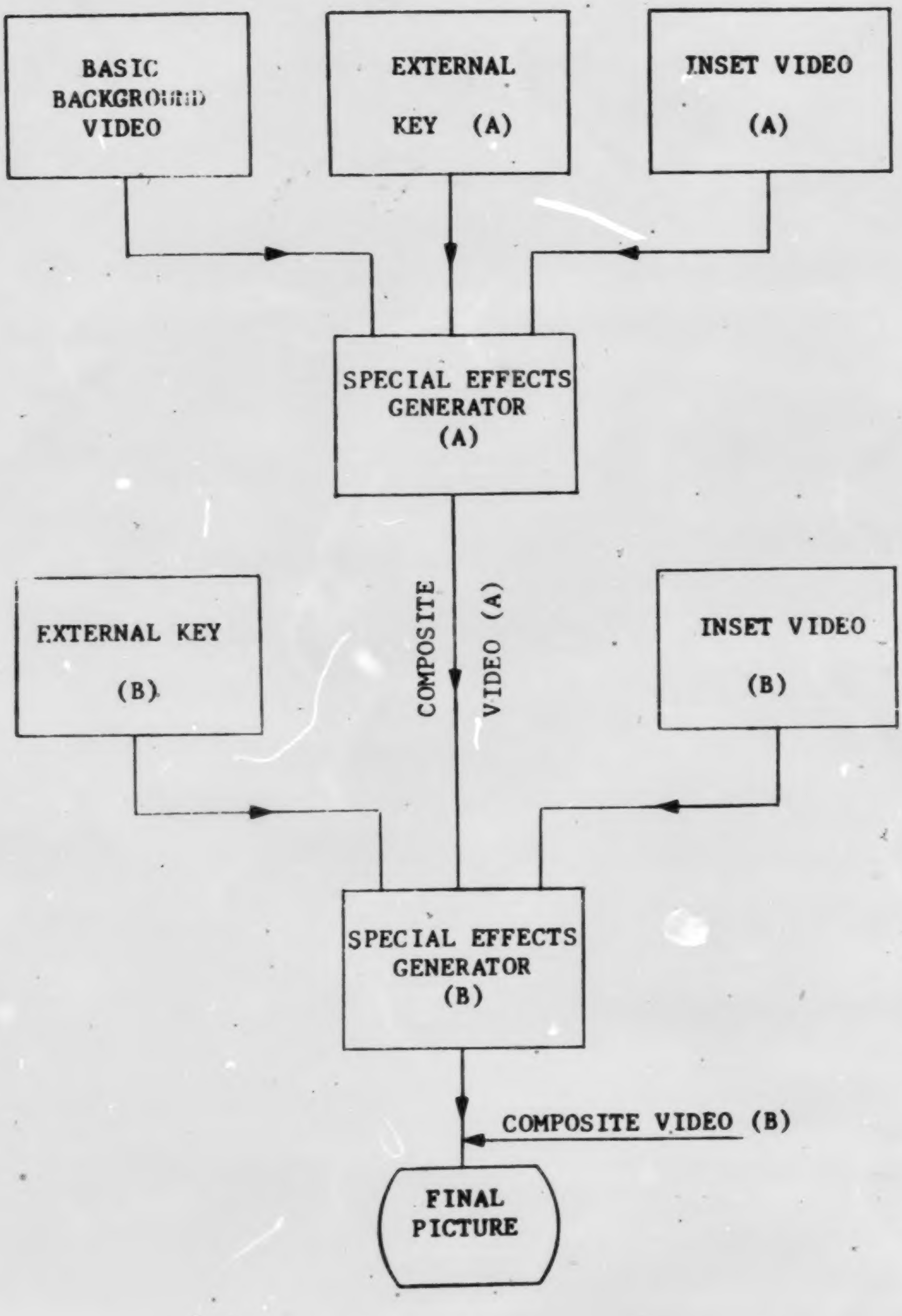

BASIC BACKGROUND VIDEO
EXTERNAL KEY (A)
INSET VIDEO (A)
SPECIAL EFFECTS GENERATOR (A)
COMPOSITE VIDEO (A)
EXTERNAL KEY (B)
INSET VIDEO (B)
SPECIAL EFFECTS GENERATOR (B)
COMPOSITE VIDEO (B)
FINAL PICTURE

Figure 55. System for Generating Composite Video

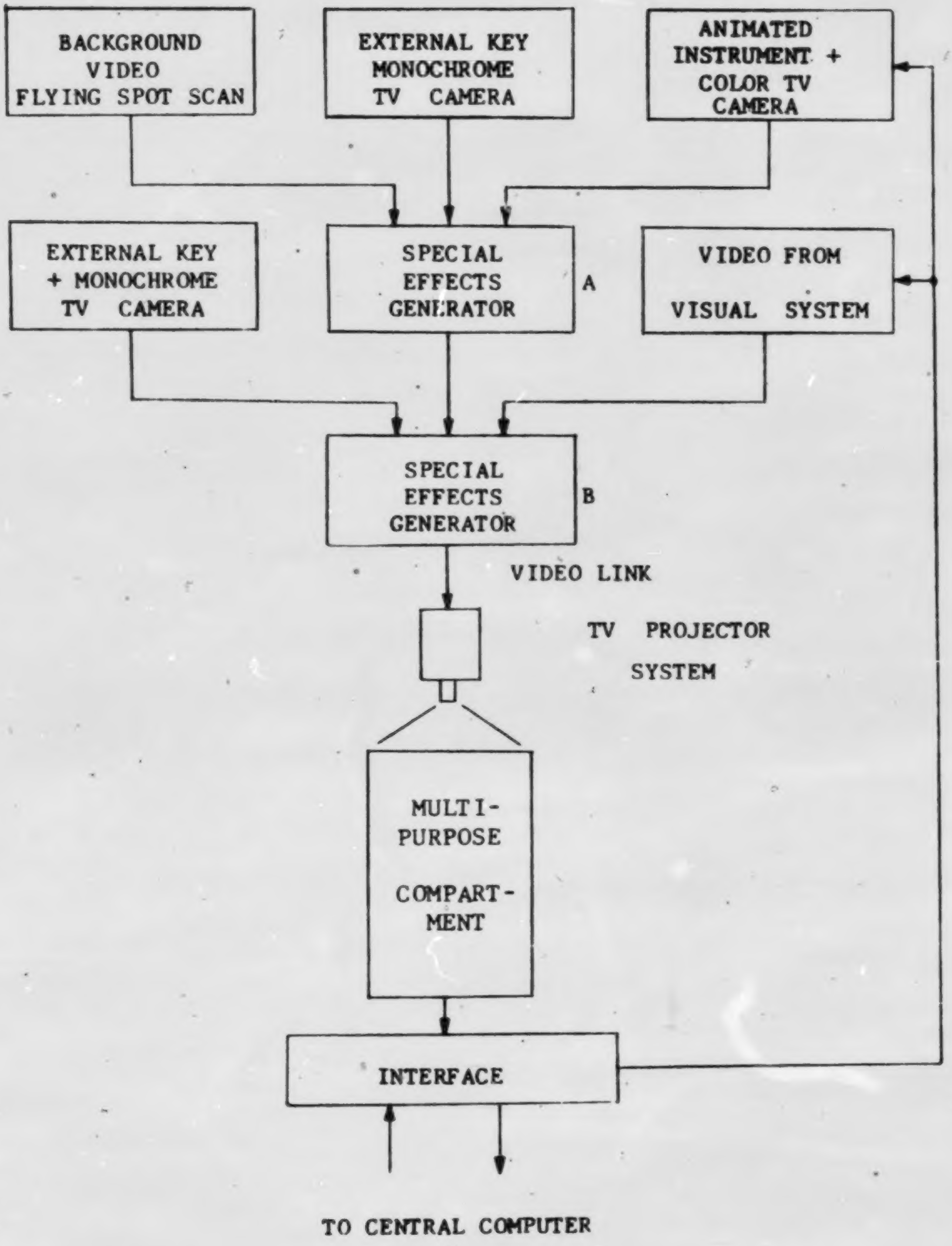

BACKGROUND VIDEO FLYING SPOT SCAN
EXTERNAL KEY MONOCHROME TV CAMERA
ANIMATED INSTRUMENT + COLOR TV CAMERA
EXTERNAL KEY + MONOCHROME TV CAMERA
SPECIAL EFFECTS GENERATOR
A
VIDEO FROM VISUAL SYSTEM
SPECIAL EFFECTS GENERATOR
B
VIDEO LINK
TV PROJECTOR SYSTEM
MULTI-PURPOSE COMPARTMENT
INTERFACE
TO CENTRAL COMPUTER

Figure 36. ETSS Configuration with Multi-Purpose Compartment

Basically the synthesized device is represented on the face of a CRT using a graphic display terminal. Special symbols, vectors and characters would be generated and animated under computer control. Since the face of the display is viewed by a TV camera equipped with zoom lens, the size of the display is relatively unimportant. However, larger diameter displays can generally accommodate more symbols. By suitable use of an external key and manipulation of the zoom lens, the desired operational display is represented on the projected display at the correct size. Operational display phosphor colors may be synthesized by use of gelatin filters or judicious use of the chromatic controls of a color TV system.

The external visual scene may also be integrated into this system. This would be generated using a TV camera-model system, or a VAMP-type visual aid being converted to a video signal. Both methods make use of relative position within the TV picture frame and an external key.

The view of an active missile in flight as seen from the launching point may be generated by a combination of the external visual scene and the graphic display terminal. The burning missile exhaust is generated by a bright spot of variable size on the graphic display. The movements of the target are represented by movements of the TV camera probe relative to the fixed-target model. The fixed-visual scene is generated by the background slide. Suitable addition and insertion techniques allow the composite scene to be generated. The computer controls the position and size of the exhaust flare and the relative position of the target relative to the observer.

Alphanumeric messages are generated by the graphic display and TV camera or by the use of a separate CRT terminal which generates a standard raster scan video signal. The size and position of messages appearing on the graphics terminal are adjustable by computer and zoom lens control. Messages appearing on the CRT terminal, with raster scan video, are not generally adjustable in size or screen position once generated.

It should be mentioned that once a basic collection of devices has been represented, any future devices may make use of the earlier experience. For example, a representation of an airspeed indicator using a single rotary pointer may be transformed into a larger diameter ship engine-room pressure indicator by simple interchanging pointers and face plates. Suitable zoom lens control determines actual size.

A TV display has one major drawback caused by the line pattern produced by the raster scan. In order to produce an acceptable display in which the line pattern does not obscure detail nor cause a noticeable pattern, a resolution of about 4 minutes of arc per effective line is required. This is determined as follows:

$$\text{Resolution/Line} = \frac{120 \times \text{FOV}}{N_L \times K}$$

where:

FOV = vertical field of view

N_L = effective number of lines

K = 0.7 for a 525-line system

= 0.8 for a 1,000-line system

= 0.9 for a 2,000-line system

For a training evaluation compartment with a 4-foot by 3-foot screen and a 2,000-line system, the subject must be seated about 4 feet away from the screen. For 1,000- or 525-line systems the subject must be seated proportionately further away.

After having determined the screen size and the distance of the subject's eyes from the screen, a photograph is made of the view from the subject's position in the operational device. It is important that the field of view of the photograph corresponds to the field of view of the subject viewing the projected scene.

The multi-purpose compartment used for this facility consists of a compartment in the shape of an oblong box approximately a right-parallelepiped. At one end is a viewing screen suitable for back projection techniques. With exception of the projection screen, the interior is lined with black nonreflective material. To augment the authenticity of the device represented, optional side consoles containing suitable switches and controls necessary for the particular experiment may be placed inside. These consoles may be fabricated from laths and hardboard, painted and illuminated by suitable interior lighting of variable intensity. Controls for feet and hands may also be placed in the compartment as required by the experiment.

As mentioned in previous sections, the video used in the final composite picture is derived from many sources, which include:

a. Basic background scene. This will, in general, be in color and will be generated using a high-quality camera and color transparency film material. The background scene is converted to color video using a high-resolution flying-spot scanner.

b. External key. This will consist of a black image on a flat white ground. The black and white areas will be viewed by a monochrome camera.

c. Inset video. This may come from a color TV camera with a high resolution, flying-spot scanner or an external video source.

d. The three video sources are combined via a special-effects generator.

e. Finally, the composite video is routed to a TV color projector such as an Eidophor or Schmidt.

The system as described has a drawback which is related to the "state of the art" TV systems. The described system for a 3 x 4-foot screen with the subject 4 feet away requires a TV system operating at 2,000 effective lines. In the next five years, it is anticipated that such a system will be developed and will become available at reasonable cost; as a result the complex will be a realizable piece of training equipment.

1.3 Universal Terminal. This study concerns ETSS peripheral devices. Several of the areas have similar requirements (documentation readout, timesharing terminal, CRT terminal, etc.). The major drawback to the use of standard

CRT terminals for documentation display is the amount of computer storage required to store text. This is an important consideration in the study.

The universal terminal will be used as an interface between an operator and the centralized computation and data storage center. It will allow the operator to communicate with the central computer and the data storage unit with an alphanumeric display. The output from the data storage unit will be displayed on a high-definition TV display. On request, either from the computer or from the operator, either the high-definition TV picture or the alphanumeric display picture may be reproduced to give a hard-copy output. A number of similar universal terminals will be attached to a common interface through which the centralized computation and data storage unit will communicate. It will be possible for the operator at the terminal to communicate with other ETSS lab areas, other terminals, or other telephone locations by interphone communications. Figure 37 (Page L-15) represents an artist's impression of the universal terminal.

The universal terminal henceforth called the terminal, will consist of components shown in Figure 38 (Page L-16). All components will be connected to the common interface.

The alphanumeric color CRT system will consist of an electronics unit and a monitor unit. The electronics unit will contain the alphanumeric character refresh memory, a data interface and control and timing and driving circuitry required to accept computer and keyboard inputs. The character generator will accept 8-bit coded characters from the refresh memory and generate the required ASCII character set. The character refresh memory will be a disc memory of sufficient size to contain a complete page of displayable characters. The control unit will respond to both control codes and character codes transmitted to the electronics unit. Control codes will be used to define the four colors for the characters following the color code. The data interface will permit transmission of 8-bit parallel characters between the computer common interface and the electronics unit.

The monitor unit will be a color TV monitor. A full page of displayed information will contain 50 lines of alphanumerics with 85 characters per line. The monitor raster scan will be in accordance with EIA RS-170 525-line TV with

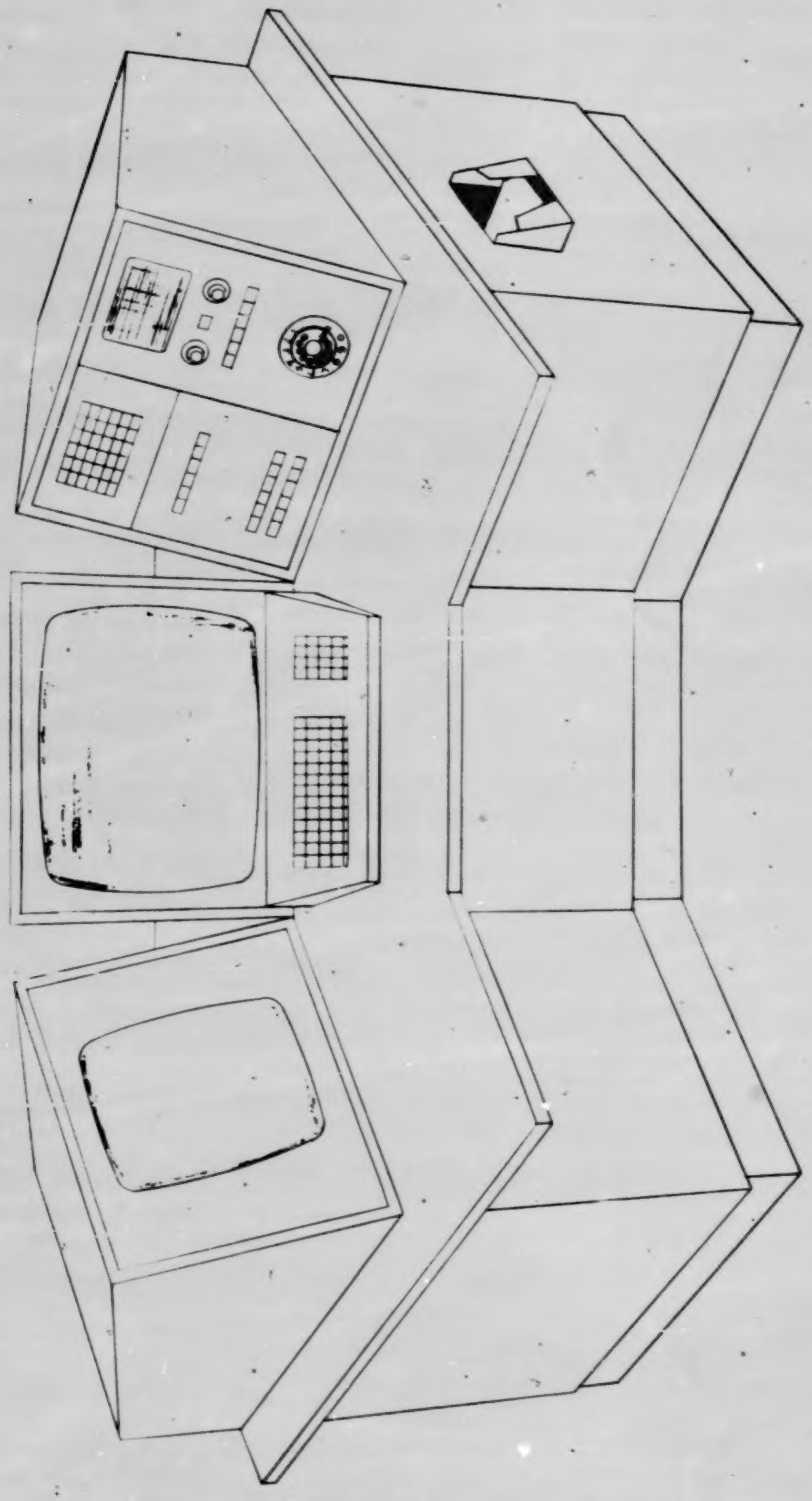


Figure 37. Artist's Impression of the Universal Terminal

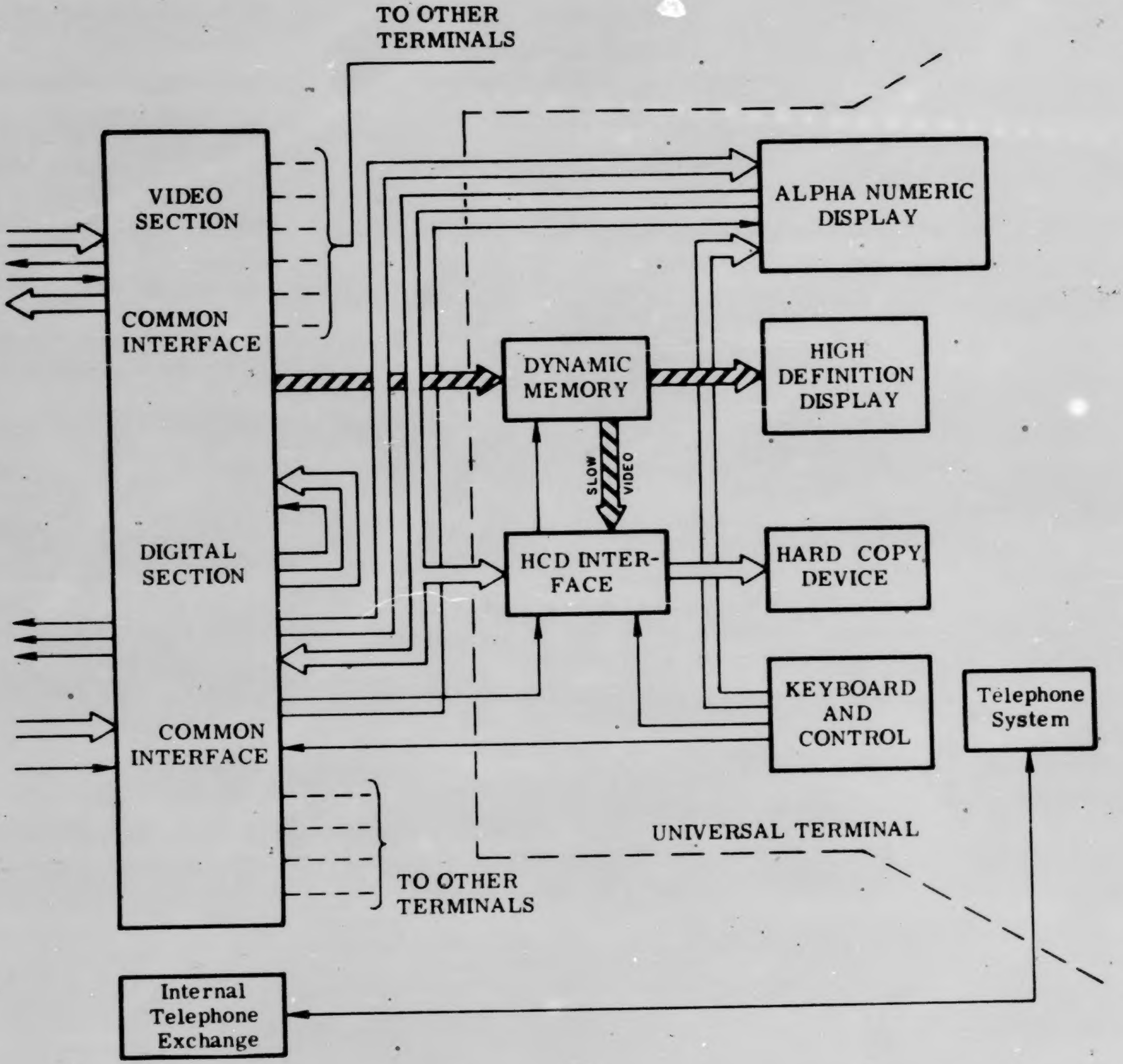

TO OTHER TERMINALS
VIDEO SECTION
COMMON INTERFACE
ALPHA NUMERIC DISPLAY
DYNAMIC MEMORY
HIGH DEFINITION DISPLAY
SLOW VIDEO
DIGITAL SECTION
HCD INTER-FACE
HARD COPY DEVICE
KEYBOARD AND CONTROL
Telephone System
COMMON INTERFACE
UNIVERSAL TERMINAL
TO OTHER TERMINALS
Internal Telephone Exchange

Figure 38. Block Diagram of the Universal Terminal

two interlaced fields per frame. Characters will be represented by a dot matrix. The displayed page will be refreshed from the display memory at 30 complete frames per second.

The keyboard will be provided with a complete set of alphabetic and numeric keys for all the symbols displayable on the monitor. In addition, cursor and function keys will be provided to enable the displayed page to be edited from the keyboard, to control the operation of the hardcopy device and to communicate with the computer common interface.

The high-definition display system will consist of a high-definition monitor and a dynamic video memory. The system will be capable of completely resolving a document page (8½ x 11 inches) in which the smallest element measures 14 mils. The high-definition monitor will have a black and white image. The resolution of the monitor will be measured at the screen corner and at the screen center and will meet the stated requirement.

The dynamic video memory will be used to generate a continuous image of the same complete frame without discernible flicker on the face of the monitor. The video memory will accept source video from the common interface and store this video to refresh the monitor when the source video is absent. The video memory will also be capable of being slowed down to give a transfer rate compatible with the input transfer rate of the hard-copy device. The dynamic memory will accept a video input from the common interface, and will provide a suitable video output to the high-definition monitor and the interface to the hard-copy device. The dynamic memory will be controlled by signals from the hard-copy device interface. The device will produce a complete TV frame from either the alphanumeric or the high-definition display in less than 2 seconds. The resultant hard-copy output will be a dry, stable black image on white paper. The resolution of the system will be compatible with that defined for the resolution of the high-definition display for the universal terminal.

The terminal will interface the hard-copy device to either the alphanumeric display or the dynamic memory. The data input to the hard-copy device interface will be of two types:

a. Slow digital video, from the dynamic memory.

b. Eight-bit parallel ASCII code from the alphanumeric display.

The output from the hard-copy device interface will be in a format acceptable to the hard-copy device.

The hard-copy device interface will receive control inputs from the keyboard and control functions directly from the common interface. It will provide suitable control signals to the dynamic memory and the alphanumeric display to allow the transfer of data.

Besides communicating with the documentation and computation center over a data line, it will be possible for a two-way conversation to be held with personnel at other laboratory locations, other terminals or external telephone locations. The terminal will be provided with a telephone dial, loudspeaker, microphone, and control buttons, these will be built into the terminal enclosure. The terminal user by choice of dial codes will also be able to page personnel. The terminal will interface to the control telephone exchange over conventional telephone lines. The only associated device will be the common interface.

1.4 Generalized Math Model. An area of special design study was concerned with the simulation of training devices in the form of mathematical models. A major area of research must provide for representative simulation of training devices to enable complete flexibility in performing high or low-fidelity experiments. This capability can include experiments performed in the following vehicle types:

1. Air Vehicles
   - a) Fixed-wing
   - b) Rotary-wing
   - c) Hovercraft
   - d) STOL
   - e) VSTOL

2. Land Vehicles
   - a) Automobiles
   - b) Tracked vehicles
   - c) Locomotive

3. Surface Vehicles

   a) Ships
   b) Amphibious vehicles
   c) Hydrofoil
   d) Air-cushion vehicles

4. Submerged Vehicles

   a) Submarines
   b) Diving bells

Simulation of the above systems as individual modules poses no serious problem. However, the need for flexibility and speed of implementation in a working ETSS eliminates this approach, as does the cost of programming. The optimum system would be the implementation of a general set of equations which allows complete flexibility in simulating any system that is proposed for an experiment. This concept of developing a math model that is utilized for any class of systems requires definition of the degree of simulation required by the experimental system. Thus the question is posed: "How much fidelity is needed for a particular simulation?" Although no measure of simulation fidelity can be attained through a general analysis, the question can be answered by inspection of the various parameters involved in the equations as opposed to what is needed for the experiment. For example, if the experiment calls for the simulation of a subsonic fixed-wing aircraft and the primary purpose of the experiment is determination of human response to a change in pitching velocity, the requirement for the coefficients of yaw, sideslip and roll might not be needed to attain an end result. In this particular case the equations of motion with respect to pitching velocity would suffice. The determination of such limiting factors must be analyzed to reach a greater definition of analytic simulation requirements.

As part of this study a generalized definition of the equations of motion for a body with respect to a six-degree-of-freedom base was analyzed as a possible solution to the problem of simulating many systems. Specific requirements relating to fidelity were not considered here. This was done because of the limited time available for this portion of the study. The objective was to determine to what degree a generalized math model could be used for the different type of vehicles (and other systems) mentioned previously. It was assumed that prior to incorporation into the ETSS a more extensive study could be performed dealing specifically with simulation fidelity if this approach proved acceptable. A preliminary model of the system for the calculation and general flow computation for the multi-purpose equations of motion was formulated. (Figure 10, Page I-23.)

This generalized set of equations which allows an experimenter to assemble a programmed math model of any vehicle he may desire is, of necessity, extremely complex. The conglomerate of submodels from which he selects and then assembles in "tinker toy" fashion must account for each and every physical manifestation associated with the motion of the whole list of vehicles to be simulated. A single program residing in the digital computer would be impractical because of its extreme size. However, it is practical to store a single program embodying the Newtonian equations of motion of a rigid body in the main computer and store all the other submodels on disc files. The executive program in the main computer will access to the disc files, retrieve the desired submodels and assemble them at the command of the experimenter. The main computer then need only be large enough to simulate the one vehicle whose assembled program is the largest of the list. The experimenter can build a program to simulate a desired vehicle by using a simple repertoire of assembly commands and inserting the physical constants (mass, inertias, force and moment coefficients, etc.) associated with his desired simulated vehicle.

Each of the vehicles can be treated either as a single rigid body or a combination of rigid bodies coupled into a single system with elastic, friction or damper coupling. The single rigid body program can be used in an iterated fashion with the results of each iteration coupled through a coupling submodel to those of the subsequent iteration until the motion of the system of bodies is determined for the instant in time of interest (standard digital techniques for real time simulation).

Figure 39, (Page I-21/I-22) shows the general computation flow. The rigid body motion equations are shown in their entirety whereas only a few typical submodule equations are shown Determination of all the submodels required for a comprehensive generalized math model is far beyond the scope of this study.

EXECUTIVE

DISK PAK PROGRAM

WEIGHT AND BALANCE FOR N BODY VEHICLE

FUEL WEIGHT: $W_{F_{a_n}} = W_{F_{T_{a_n}}} - \int W_{f_{a_n}}\,dt$ Where $W_{f_{a_n}}$ is fuel expenditure rate

BALLAST WEIGHT: $W_{B_{c_n}} = W_{B_{T_{c_n}}} - \int W_{b_{c_n}}\,dt$ Where $W_{b_{c_n}}$ is ballast pumping rate*

STORES RATE: $W_{S_{B_n}} = \sum_{b=1}^{B} (500b)\,(W_{s_{b_n}})$ Where 500b is discrete for store release

GROSS WEIGHT: $W_{G_n} = W_{G_{o_n}} + \sum_{a=1}^{A} W_{F_{a_n}} + W_{B_{c_n}} + \sum_{c=1}^{C} W_{B_{c_n}} - W_{S_{B_n}}$

CG LOCATION: $L_{x_n} = \frac{1}{W_{G_n}} \left[W_{G_{o_n}} (X_o)_n + \sum_{a=1}^{A} W_{F_{a_n}} (X_a)_n + \sum_{c=1}^{C} W_{B_{c_n}} (X_c)_n + \sum_{b=1}^{B} (500b)(W_{S_{b_n}})\,(X_b)_n \right]$

$L_{y_n} = \frac{1}{W_{G_n}} \left[W_{G_{o_n}} (Y_o)_n + \sum_{a=1}^{A} W_{F_{a_n}} (Y_a)_n + \sum_{c=1}^{C} W_{B_{c_n}} (Y_c)_n + \sum_{b=1}^{B} (500b)(W_{S_{b_n}})\,(Y_b)_n \right]$

$L_{z_n} = \frac{1}{W_{G_n}} \left[W_{G_{o_n}} (z_o)_n + \sum_{a=1}^{A} W_{F_{a_n}} (z_a)_n + \sum_{c=1}^{C} W_{B_{c_n}} (z_c)_n + \sum_{b=1}^{B} (500b)(W_{S_{b_n}})\,(z_b)_n \right]$

MOMENTS OF INERTIA: $I_{xx_n} = I_{xx_o} + \sum_{a=1}^{A} K^{①}_{a_n} W_{F_{a_n}} + \sum_{c=1}^{C} K^{②}_{C_n} W_{B_{c_n}} - \sum_{b=1}^{B} (500b)\,K^{③}_{b_n} W_{S_{b_n}}$

$I_{yy_n} = I_{yy_o} + \sum_{a=1}^{A} K^{④}_{a_n} W_{F_{a_n}} + \sum_{c=1}^{C} K^{⑤}_{C_n} W_{B_{c_n}} - \sum_{b=1}^{B} (500b)\,K^{⑥}_{b_n} W_{S_{b_n}}$

$I_{zz_n} = I_{zz_o} + \sum_{a=1}^{A} K^{⑦}_{a_n} W_{F_{a_n}} + \sum_{c=1}^{C} K^{⑧}_{C_n} W_{B_{c_n}} - \sum_{b=1}^{B} (500b)\,K^{⑨}_{b_n} W_{S_{b_n}}$

FINAL WEIGHT AND BALANCE SOLUTIONS DEPEND UPON COMBINING THE ABOVE SOLUTIONS FOR EACH OF THE N BODIES TOGETHER IN A MANNER WHICH ACCURATELY REFLECTS THE NUMBER OF DEGREES OF FREEDOM OF EACH BODY POSSESSES WITH RESPECT TO THE OTHER BODIES.

WEIGHT AND BALANCE COMBINATION EXAMPLE

BODY M AND BODY N BODY AXIS SYSTEMS ARE COINCIDENT AND BODY M IS FREE TO ROTATE ABOUT BODY N'S X AXIS ONLY. LET N=1 AND M=2.

THE CG LOCATION FOR A FORCE ACTING ON BODY M PARALLEL TO THE Y AXIS BUT NOT IN THE XY PLANE IS GIVEN SIMPLY BY

$$\left.\begin{matrix} L_{x_2} \\ L_{y_2} \\ L_{z_2} \end{matrix}\right\} \text{AS SOLVED FOR ABOVE } (n = 2)$$

THE CG LOCATION FOR A FORCE ACTING ON BODY M PARALLEL TO THE X AXIS BUT NOT IN THE XY PLANE IF GIVEN BY

$$W_{G_{mn}} = \sum_{n=1}^{2} W_{G_N}$$

$$L_{x_{mn}} = \frac{1}{W_{G_{mn}}} \left[\sum_{n=1}^{2} W_{G_n} (X_n) \right]$$

$$L_{y_{mn}} = \frac{1}{W_{G_{mn}}} \left[\sum_{n=1}^{2} W_{G_n} (y_n) \right]$$

$$L_{z_{mn}} = \frac{1}{W_{G_{mn}}} \left[\sum_{n=1}^{2} W_{G_n} (z_n) \right]$$

SUMMATION OF MOMENTS

$m_{x_n} = cm_{l_n} + m_{x_{a_n}}$

$m_{y_n} = cm_{m_n} + m_{y_{a_n}}$

$m_{z_n} = cm_{n_n} + m_{z_{a_n}}$

SUMMATION OF

$F_{x_n} = cF_{x_n} +$

$F_{y_n} = cF_{y_n} + F_{y}$

$F_{z_n} = cF_{z_n} + F_{z}$

ANGULAR ACCELERATION VECTOR COMPONENTS

$$\dot p_{a_n} = \frac{1}{I_{xx_n}} \left[M_{x_n} + (I_{yy_n} - I_{zz_n}) q_{a_n} r_{a_n} + I_{xy_n} (\dot q_{a_n} - r_{a_n} p_{a_n}) + I_{zx_n} (\dot r_{a_n} + p_{a_n} q_{a_n}) + I_{yz_n} (q_{a_n}^2 - r_{a_n}^2) \right]$$

$$\dot q_{a_n} = \frac{1}{I_{yy_n}} \left[M_{y_n} + (I_{zz_n} - I_{xx_n}) r_{a_n} p_{a_n} + I_{yz} (\dot r_{a_n} - p_{a_n} q_{a_n}) + I_{xy} (\dot p_{a_b} + q_{a_n} r_{a_n}) + I_{zx_n} (r_{a_n}^2 - p_{a_n}^2) \right]$$

$$\dot r_{a_n} = \frac{1}{I_{zz_n}} \left[M_{z_n} + (I_{xx_n} - I_{yy_n}) p_{a_n} q_{a_n} + I_{zx_n} (\dot p_{a_n} - q_{a_n} r_{a_n}) + I_{yz_n} (\dot q_{a_n} + r_{a_n} p_{a_n}) + I_{xy_n} (p_{a_n}^2 - q_{a_n}^2) \right]$$

ANGULAR RATES

$p_{b_n} = \int \dot p_{b_n}\,dt + p_{b_n}$

$q_{b_n} = \int \dot q_{b_n}\,dt + q_{b_n}$

$r_{b_n} = \int \dot r_{b_n}\,dt + r_{b_n}$

QUATERNION RATES

$\dot e_{1_n} = 1/2\,[-e_{4_n} p_{b_n} - e_{3_n} q_{b_n} - e_{2_n}$

$+ K_1 e_{1_n} (1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2)]$

$\dot e_{2_n} = 1/2\,[-e_{3_n} p_{b_n} + e_{4_n} q_{b_n} + e_{1_n} r_{b_n}$

$+ K_1 e_{2_n} (1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2)]$

$\dot e_{3_n} = 1/2\,[e_{2_n} p_{b_n} - e_{1_n} q_{b_n} - e_{4_n} r_{b_n}$

$+ K_1 e_{3_n} (1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2)]$

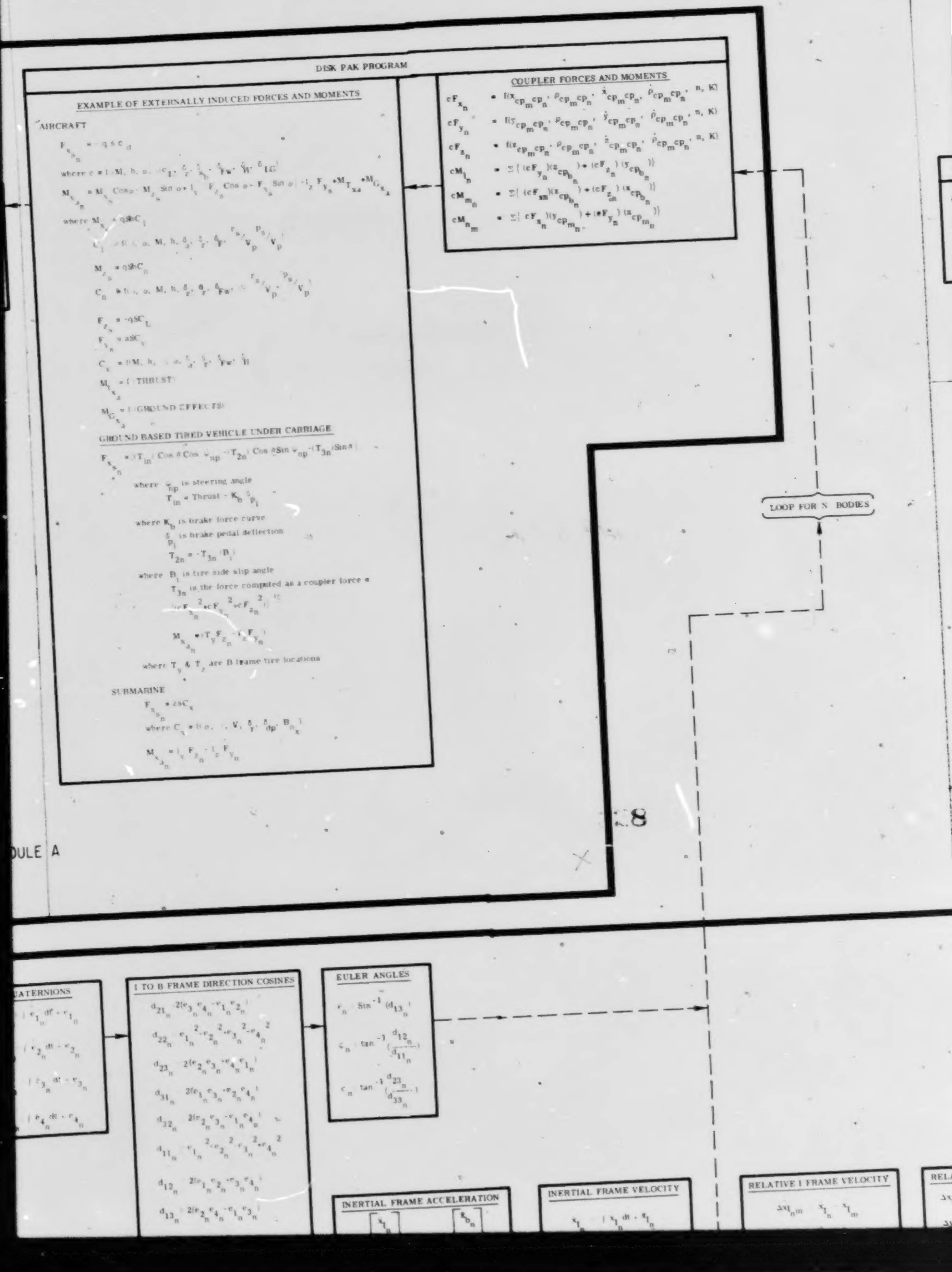
$\dot e_{4_n} = 1/2\,[e_{1_n} p_{b_n} - e_{2_n} q_{b_n} + e_{3_n} r_{b_n}$

$+ K_1 e_{4_n} (1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2)]$

TRANSLATIONAL ACCELERATION VECTOR COMPONENTS

$$\ddot x_{b_n} = -g \frac{(F_{x_n})}{m_n}$$

$$\ddot y_{b} = -g(F_{y}$$



DISK PAK PROGRAM

EXAMPLE OF EXTERNALLY INDUCED FORCES AND MOMENTS

AIRCRAFT

$F_{x_{s_n}} = -q\,s\,c_d$

where $c = f(M, h, \alpha, (c_1, \delta_r, \delta_b, \delta_{Fw}, \delta_H, \delta_{LG})$

$M_{x_{a_n}} = M_{x_s}\,\mathrm{Cos}\,\alpha - M_{z_s}\,\mathrm{Sin}\,\alpha + l_y\,(F_{z_s}\,\mathrm{Cos}\,\alpha - F_{x_s}\,\mathrm{Sin}\,\alpha) - l_z\,F_{y_s} + M_{T_{xa}} + M_{G_{x_a}}$

where $M_{x_s} = qSbC_l$

$C_l = f(\beta, \alpha, M, h, \delta_a, \delta_r, \delta_F, {r_s}/{V_p}, {p_s}/{V_p})$

$M_{z_s} = qSbC_n$

$C_n = f(\beta, \alpha, M, h, \delta_r, \delta_r, \delta_{Fw}, {r_s}/{V_p}, {p_s}/{V_p})$

$F_{z_s} = -qSC_L$

$F_{y_s} = qSC_y$

$C_x = f(M, h, \alpha, \delta_a, \delta_r, \delta_{Fw}, \delta_H)$

$M_{T_{x_a}} = f\,(\mathrm{THRUST})$

$M_{G_{x_a}} = f\,(\mathrm{GROUND\ EFFECTS})$

GROUND BASED TIRED VEHICLE UNDER CARRIAGE

$F_{x_{s_n}} = (T_{1n})\,\mathrm{Cos}\,\theta\,\mathrm{Cos}\,\psi_{np} - (T_{2n})\,\mathrm{Cos}\,\theta\,\mathrm{Sin}\,\psi_{np} - (T_{3n})\,\mathrm{Sin}\,\theta)$

where ψ_{np} is steering angle

$T_{1n} = \mathrm{Thrust} - K_b\,\delta_{p_i}$

where K_b is brake force curve

δ_{p_i} is brake pedal deflection

$T_{2n} = -T_{3n}\,(B_i)$

where B_i is tire side slip angle

T_{3n} is the force computed as a coupler force =

$(cF_{x_n}^2 + cF_{y_n}^2 + cF_{z_n}^2)^{1/2}$

$M_{x_{a_n}} = (T_y F_{z_n} - T_z F_{y_n})$

where T_y & T_z are B frame tire locations

SUBMARINE

$F_{x_{s_n}} = \bar{q}SC_x$

where $C_x = f(\alpha, \beta, V, \delta_r, \delta_{dp}, B_{o_x})$

$M_{x_{a_n}} = l_y\,F_{z_n} - l_z\,F_{y_n}$

COUPLER FORCES AND MOMENTS

$cF_{x_n} = f(x_{cp_m cp_n}, \rho_{cp_m cp_n}, \dot{x}_{cp_m cp_n}, \dot{\rho}_{cp_m cp_n}, n, K)$

$cF_{y_n} = f(y_{cp_m cp_n}, \rho_{cp_m cp_n}, \dot{y}_{cp_m cp_n}, \dot{\rho}_{cp_m cp_n}, n, K)$

$cF_{z_n} = f(z_{cp_m cp_n}, \rho_{cp_m cp_n}, \dot{z}_{cp_m cp_n}, \dot{\rho}_{cp_m cp_n}, n, K)$

$cM_{l_n} = \Sigma\{(cF_{y_n})(z_{cp_{b_n}}) + (cF_{z_n})(y_{cp_{b_n}})\}$

$cM_{m_n} = \Sigma\{(cF_{xn})(z_{cp_{b_n}}) + (cF_{zn})(x_{cp_{b_n}})\}$

$cM_{n_m} = \Sigma\{(cF_{x_n})(y_{cp_{m_n}}) + (cF_{y_n})(x_{cp_{m_n}})\}$

LOOP FOR N BODIES

.8

DULE A

UATERNIONS

$\int \dot{e}_{1_n}\,dt + e_{1_n}$

$\int \dot{e}_{2_n}\,dt + e_{2_n}$

$\int \dot{e}_{3_n}\,dt + e_{3_n}$

$\int \dot{e}_{4_n}\,dt + e_{4_n}$

I TO B FRAME DIRECTION COSINES

$d_{21_n} = 2(e_{3_n} e_{4_n} - e_{1_n} e_{2_n})$

$d_{22_n} = e_{1_n}^2 - e_{2_n}^2 + e_{3_n}^2 - e_{4_n}^2$

$d_{23_n} = 2(e_{2_n} e_{3_n} + e_{4_n} e_{1_n})$

$d_{31_n} = 2(e_{1_n} e_{3_n} + e_{2_n} e_{4_n})$

$d_{32_n} = 2(e_{2_n} e_{3_n} - e_{1_n} e_{4_n})$

$d_{11_n} = e_{1_n}^2 + e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2$

$d_{12_n} = 2(e_{1_n} e_{2_n} + e_{3_n} e_{4_n})$

$d_{13_n} = 2(e_{2_n} e_{4_n} - e_{1_n} e_{3_n})$

EULER ANGLES

$\theta_n = \mathrm{Sin}^{-1}(d_{13_n})$

$\psi_n = \tan^{-1}\left(\frac{d_{12_n}}{d_{11_n}}\right)$

$\phi_n = \tan^{-1}\left(\frac{d_{23_n}}{d_{33_n}}\right)$

INERTIAL FRAME ACCELERATION

$\begin{bmatrix} \ddot{x}_{I_n} \end{bmatrix}$ $\begin{bmatrix} \ddot{x}_{b_n} \end{bmatrix}$

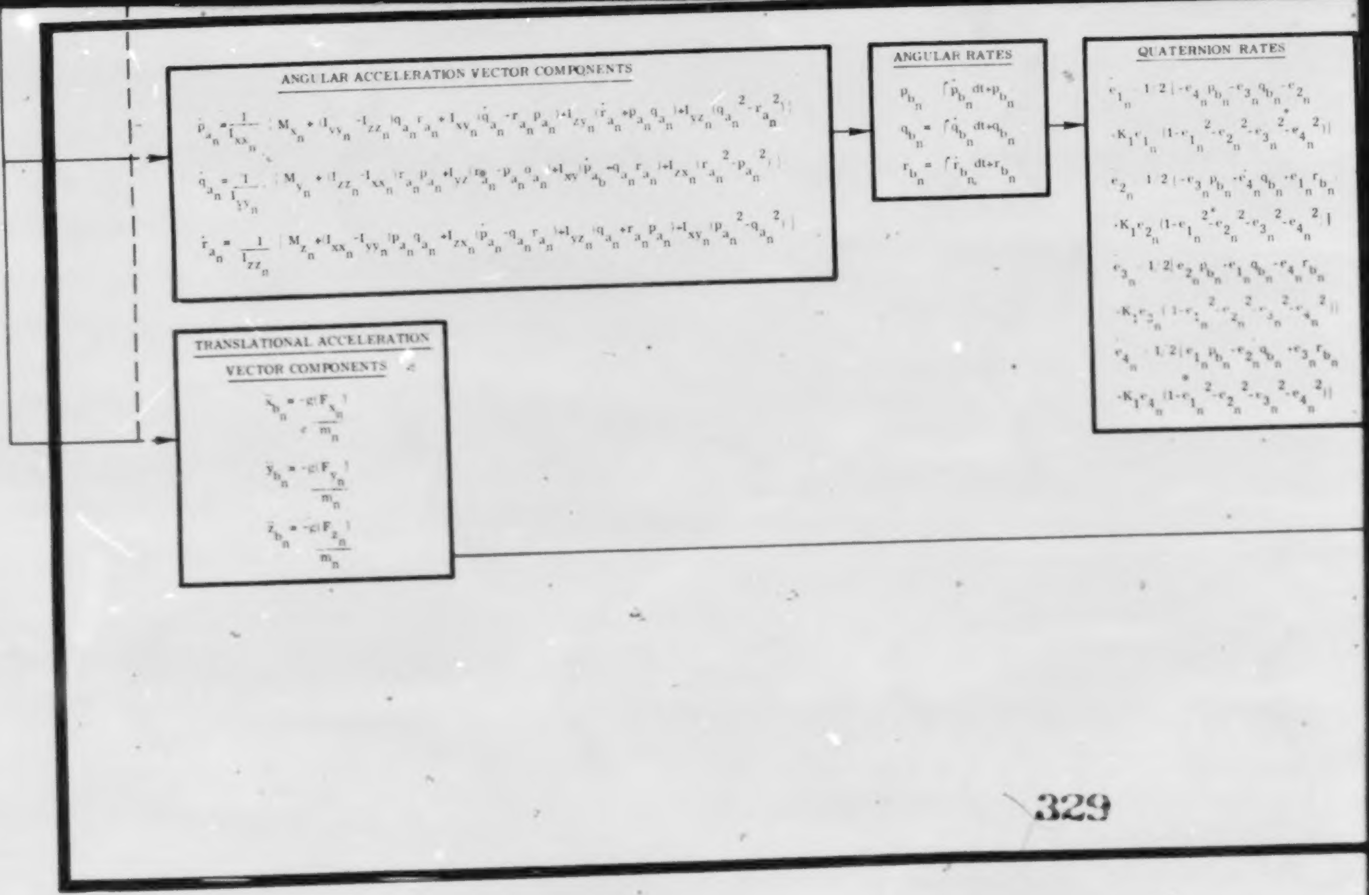
INERTIAL FRAME VELOCITY

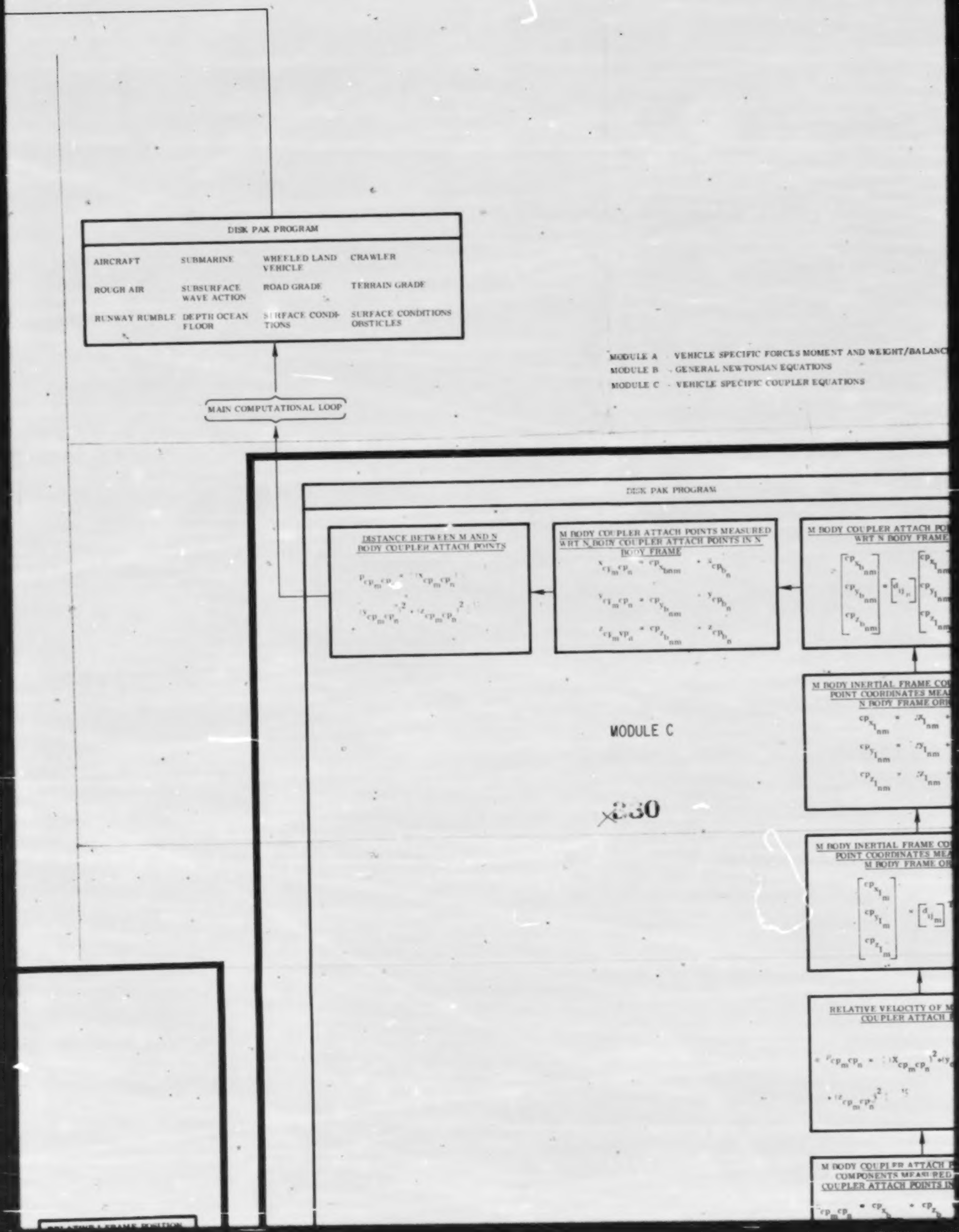
$\dot{x}_{I_n} = \int \ddot{x}_{I_n}\,dt + \dot{x}_{I_n}$

RELATIVE I FRAME VELOCITY

$\Delta \dot{x}_{I_{nm}} = \dot{x}_{I_n} - \dot{x}_{I_m}$

RELA


ANGULAR ACCELERATION VECTOR COMPONENTS
$\dot{p}_{a_n} = \frac{1}{I_{xx_n}}[M_{x_n} + (I_{yy_n} - I_{zz_n})q_{a_n} r_{a_n} + I_{xy_n}(\dot{q}_{a_n} - r_{a_n} p_{a_n}) + I_{zy_n}(\dot{r}_{a_n} + p_{a_n} q_{a_n}) + I_{yz_n}(q_{a_n}^2 - r_{a_n}^2)]$
$\dot{q}_{a_n} = \frac{1}{I_{yy_n}}[M_{y_n} + (I_{zz_n} - I_{xx_n})r_{a_n} p_{a_n} + I_{yz}(\dot{r}_{a_n} - p_{a_n} q_{a_n}) + I_{xy}(\dot{p}_{a_b} - q_{a_n} r_{a_n}) + I_{zx_n}(r_{a_n}^2 - p_{a_n}^2)]$
$\dot{r}_{a_n} = \frac{1}{I_{zz_n}}[M_{z_n} + (I_{xx_n} - I_{yy_n})p_{a_n} q_{a_n} + I_{zx_n}(\dot{p}_{a_n} - q_{a_n} r_{a_n}) + I_{yz_n}(\dot{q}_{a_n} + r_{a_n} p_{a_n}) + I_{xy_n}(p_{a_n}^2 - q_{a_n}^2)]$
ANGULAR RATES
$p_{b_n} = \int \dot{p}_{b_n} dt + p_{b_n}$
$q_{b_n} = \int \dot{q}_{b_n} dt + q_{b_n}$
$r_{b_n} = \int \dot{r}_{b_n} dt + r_{b_n}$
QUATERNION RATES
$\dot{e}_{1_n} = 1/2(-e_{4_n} p_{b_n} - e_{3_n} q_{b_n} - e_{2_n}$
$+ K_1 e_{1_n}(1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2))$
$\dot{e}_{2_n} = 1/2(-e_{3_n} p_{b_n} + e_{4_n} q_{b_n} + e_{1_n} r_{b_n}$
$+ K_1 e_{2_n}(1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2))$
$\dot{e}_{3_n} = 1/2(e_{2_n} p_{b_n} + e_{1_n} q_{b_n} - e_{4_n} r_{b_n}$
$+ K_1 e_{3_n}(1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2))$
$\dot{e}_{4_n} = 1/2(e_{1_n} p_{b_n} - e_{2_n} q_{b_n} + e_{3_n} r_{b_n}$
$+ K_1 e_{4_n}(1 - e_{1_n}^2 - e_{2_n}^2 - e_{3_n}^2 - e_{4_n}^2))$
TRANSLATIONAL ACCELERATION VECTOR COMPONENTS
$\ddot{x}_{b_n} = -g(\frac{F_{x_n}}{m_n})$
$\ddot{y}_{b_n} = -g(\frac{F_{y_n}}{m_n})$
$\ddot{z}_{b_n} = -g(\frac{F_{z_n}}{m_n})$


DISK PAK PROGRAM
AIRCRAFT
SUBMARINE
WHEELED LAND VEHICLE
CRAWLER
ROUGH AIR
SUBSURFACE WAVE ACTION
ROAD GRADE
TERRAIN GRADE
RUNWAY RUMBLE
DEPTH OCEAN FLOOR
SURFACE CONDITIONS
SURFACE CONDITIONS OBSTICLES
MAIN COMPUTATIONAL LOOP
DISK PAK PROGRAM
DISTANCE BETWEEN M AND N BODY COUPLER ATTACH POINTS
M BODY COUPLER ATTACH POINTS MEASURED WRT N BODY COUPLER ATTACH POINTS IN N BODY FRAME
M BODY COUPLER ATTACH PO
WRT N BODY FRAME
M BODY INERTIAL FRAME CO
POINT COORDINATES MEA
N BODY FRAME OR
MODULE C
M BODY INERTIAL FRAME CO
POINT COORDINATES MEA
M BODY FRAME OR
RELATIVE VELOCITY OF M
COUPLER ATTACH
M BODY COUPLER ATTACH P
COMPONENTS MEASURED
COUPLER ATTACH POINTS IN

MODULE A - VEHICLE SPECIFIC FORCES MOMENT AND WEIGHT/BALANC
MODULE B - GENERAL NEWTONIAN EQUATIONS
MODULE C - VEHICLE SPECIFIC COUPLER EQUATIONS

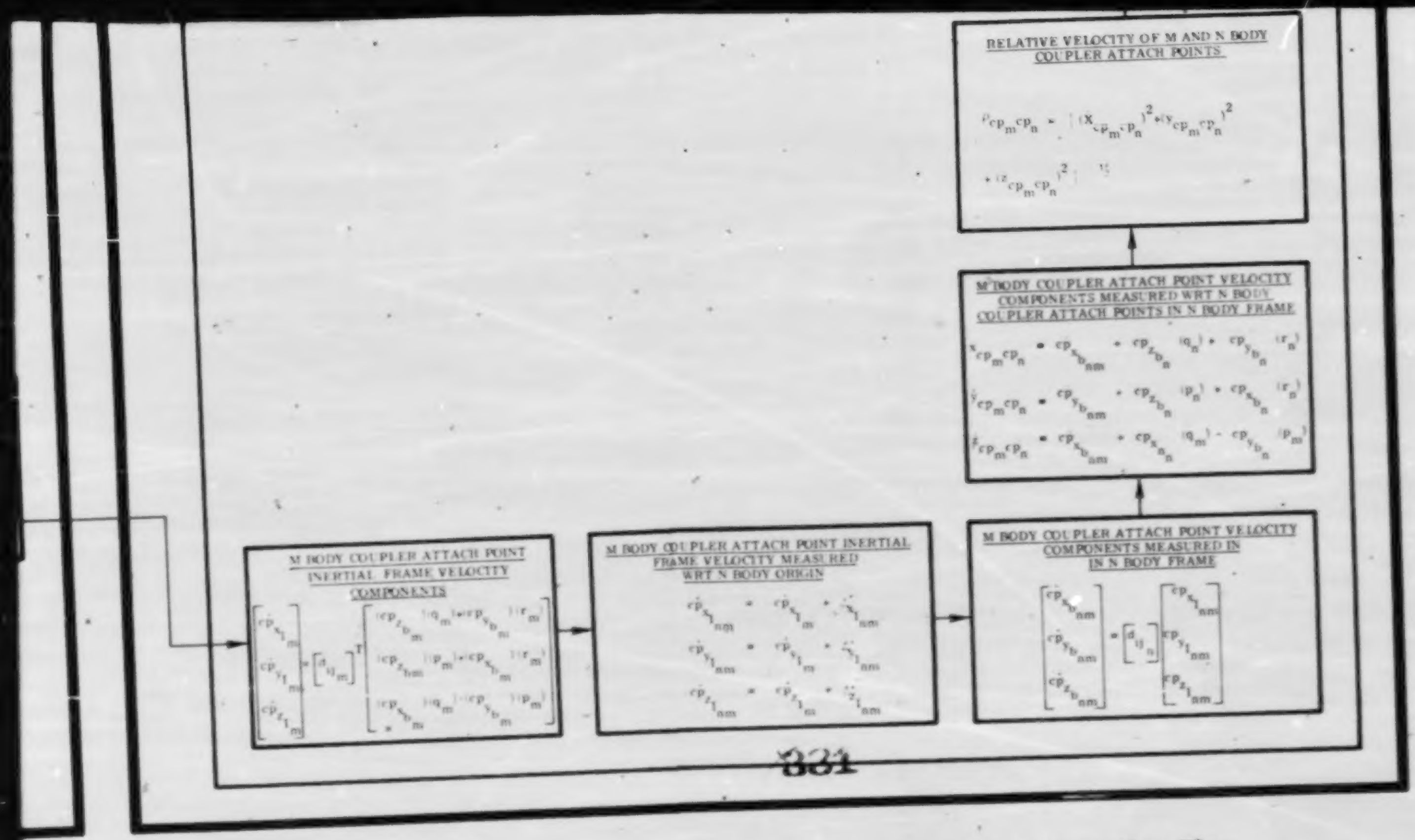

RELATIVE VELOCITY OF M AND N BODY COUPLER ATTACH POINTS
M BODY COUPLER ATTACH POINT VELOCITY COMPONENTS MEASURED WRT N BODY COUPLER ATTACH POINTS IN N BODY FRAME
M BODY COUPLER ATTACH POINT INERTIAL FRAME VELOCITY COMPONENTS
M BODY COUPLER ATTACH POINT INERTIAL FRAME VELOCITY MEASURED WRT N BODY ORIGIN
M BODY COUPLER ATTACH POINT VELOCITY COMPONENTS MEASURED IN IN N BODY FRAME

Figure 39. Generalized EOM Computation Flow

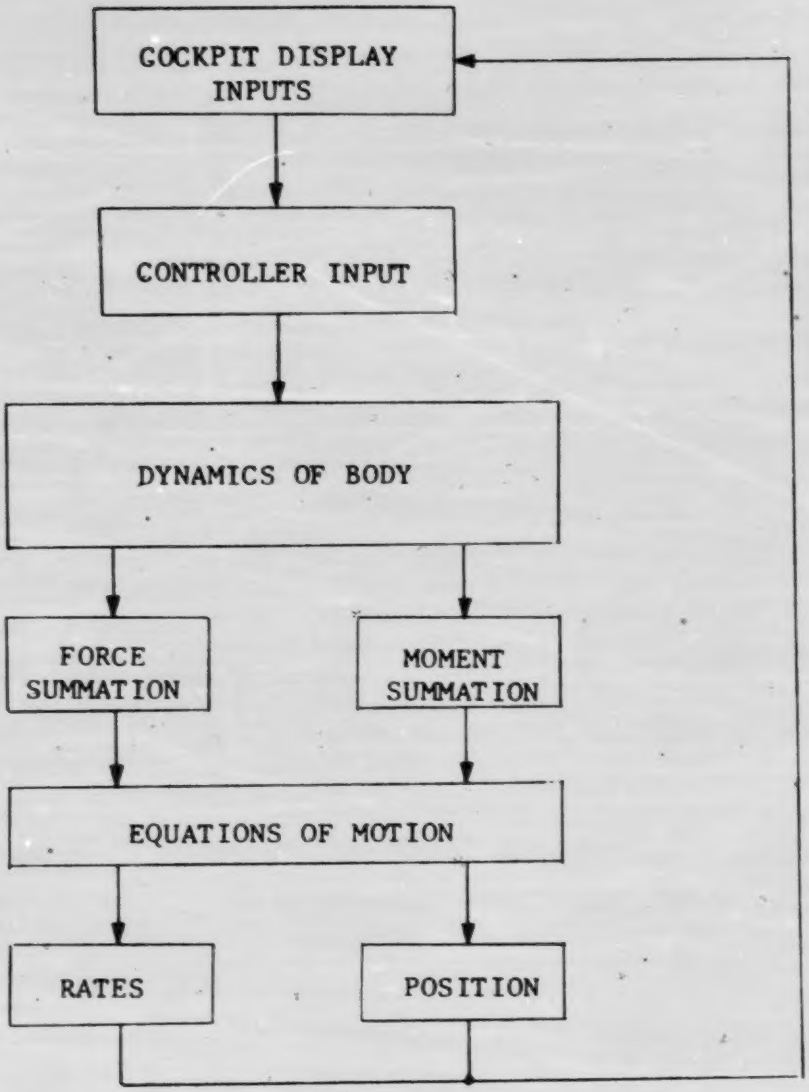

COCKPIT DISPLAY INPUTS
CONTROLLER INPUT
DYNAMICS OF BODY
FORCE SUMMATION
MOMENT SUMMATION
EQUATIONS OF MOTION
RATES
POSITION

Figure 40. Generalized Math Model Block Diagram

1.5 Universal Audio-Visual Device. Another area of special study was concerned with combining the various audio-visual capabilities into one device. The functions to be incorporated are tabulated in Section IV.

Figure 41 (Page L-24 (below)) shows the general arrangement of this device.

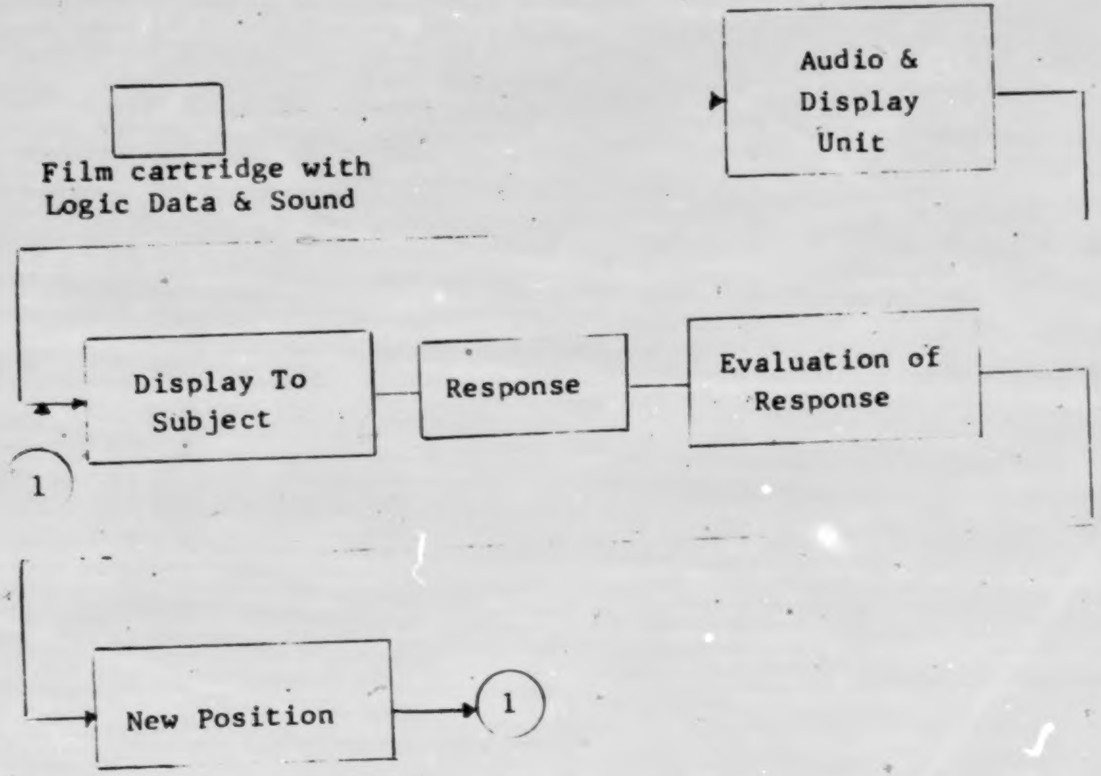

Audio & Display Unit
Film cartridge with Logic Data & Sound
Display To Subject
Response
Evaluation of Response
1
New Position
1

Figure 41. Universal Audio-Visual Device Schematic

The display unit consists of a rear projection screen, logical circuitry, computer compatible terminals, audio circuitry, cartridge receptacle, responder input and housing. The device has the capability to jump forward and backward on the film strip, based on response. The "programming" contained on the film strip or coding could be magnetic or optical. Filmed sequences can be as long as required. The data required for operation is read off the required track and stored. Each film frame would be made up as shown in Figure 42 (Page L-25).

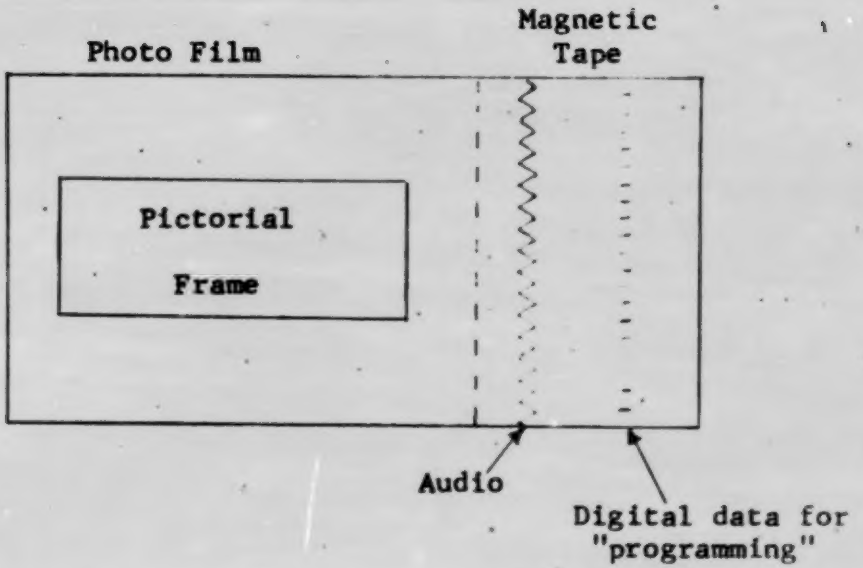


Photo Film
Magnetic Tape
Pictorial Frame
Audio
Digital data for "programming"

Figure 42. Typical Frame Content

A standard cartridge could be used but one using the "Newell principle" (See Figure 43, Page L-26) might be better. The hardware elements required for this system are:

1. Projection optics
2. Light source
3. Cartridge
4. Cartridge receptacle
5. Responder-type input
6. Digital memory
7. Simple control logic for film movement
8. Audio playback circuits
9. Speakers
10. Data channels for hookup to computer

SPECIFICATIONS:

Tape Speeds:
960/480/240/120/60/30/15 ips
Bi-directional. Switch selectable.

Equalization:
Any two speeds electrically switched from front panel.

Start-Stop Time:
1.5 sec. maximum at 960 ips to within flutter specifications. Proportionately less at lower speeds. 100 msec. minimum.

Turnaround Time:
2.0 sec. maximum at 960 ips, to within flutter specifications. Proportionately less at lower speeds. 150 msec. minimum.

Flutter (cumulative **peak-to-peak**)*:
0.05% maximum at 960 ips, from 0.2 Hz to 10 kHz:
0.1% maximum at 120 ips, from 0.2 Hz to 10 kHz:

Dynamic Skew:
±0.5 μsec. between tracks maximum at 960 ips.

Head Configuration:
2 channel record/reproduce stack.

Number of Tracks:
42 on ¼-inch tape.

Head Gap Scatter:
±50 microinches maximum.

Head Life:
In excess of 250 000 ips × hours.

Frequency **Response***

960 ips	*250–15 000*	*kHz*
480 ips	*125–7 500*	*kHz*
240 ips	*60–4 000*	*kHz*
120 ips	*30–2 000*	*kHz*
60 ips	*15–1 000*	*kHz*
30 ips	*7.5–500*	*kHz*
15 ips	*4.0–250*	*kHz*

Signal-to-Noise Ratio (**RMS/RMS**)*:
20 dB minimum

Intertrack Crosstalk:
25 dB minimum

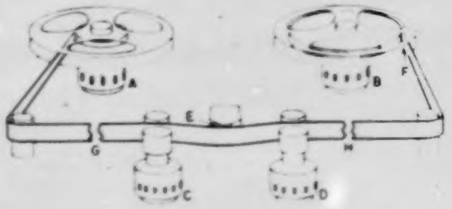
3rd Harmonic Distortion:
1% maximum

Size:
35½" h x 19" w x 20" d

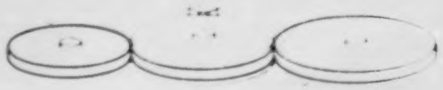
Weight:
250 lbs.

Power:
115/230 volts ±10%, 48 to 400 Hz, 600 VA average (1600 VA maximum surge).

*Using Newell Tape PN-11613. Lower bandwidth limit determined by intertrack crosstalk requirements.



Conventional Bi-directional Tape Transport
Requires a multiplicity of motors (A, B, C, D) or else a complex driving system to transfer power. Tape is unsupported through most of its length between supply and take-up reel; Air is entrapped particularly as speeds are increased, at head (E) and in take-up reel (F), resulting in loss of performance, poor tape "pack"; For fast start-stop operation, mechanical buffer systems are required at (G) and (H) because inertia of system coupled through the tape itself is too great. The tape is thus subjected to undesirable pressures and stresses along its path



Newell Tape Transport
A proprietary tape-tensioning system requires that the tape is transported in a continuously supported manner past the head from roll to roll. Supply and take-up rolls have minimum inertia (through elimination of flanges); only a single drive motor is required (which in pancake design can be integral with the capstan-drum); no torque motors, belts, or brakes are needed; tape is guided and packed with extreme uniformity; reversal of direction is accomplished extremely rapidly, without tape distortion

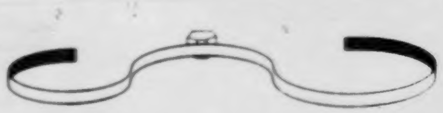


Figure 43. Tape Recorder Drive Utilizing the "Newell Principle"

APPENDIX M

COMPUTER REQUIREMENTS

This appendix analyzes requirements for the ETSS computer complex and interface system. There are two proven methods of accomplishing simulation computations, digital and analog. The digital computer is considered to be superior because of long-term accuracy, increased availability and adaptability. For these reasons, digital computers are used in most modern simulators. It is not uncommon, however, for a part of the computational task to be accomplished by analog circuitry external to the digital computer. Some of the factors that might influence computations outside the digital computer are:

a. **Frequency Response** - Where the equations for a system exhibit frequency characteristics in excess of several cycles per second, the computer time is out of proportion to the complexity of the system. In such cases, analog techniques can offer a substantial problem reduction. Availability can also be improved if a reduction in hardware is achieved.

b. **Cost Effectiveness** - Where the equations for a system are quite simple, it is sometimes less expensive to implement the equations directly in analog form instead of providing the data conversion equipment necessary to get the appropriate parameters in and out of the computer. An example of this is simulation of an electrical system.

c. **Computer Sizing** - With the proliferation of digital computers and associated memory and I/O devices, it is usually possible to select a system which can perform the computational task. However, this system can exceed some economic break-even point. An example would be a computational task slightly larger than could be handled by a single computer. Some analog computation might eliminate need for a second computer.

Of the above reasons, only the first is valid; the others appear to be reasonable at first glance, but upon further examination are generally found to be false economies. The use of external analog computations to minimize interface hardware, although appearing to reduce cost and improve availability, actually does neither. It is true that a large amount of interface equipment and computer memory could be eliminated. However, digital computers are highly reliable solid-state equipment, whereas added hardware (relays and operational amplifiers) are less reliable. Therefore, overall reliability may be decreased.

In addition, maintainability of the system suffers. Analog computers require periodic adjustments and are more subject to drift and other errors than digital hardware. Generally, the additional maintenance expense necessitated by use of analog computing equipment offsets the saving in hardware.

The major reason for selection of a digital system is inherent in the function of the ETSS. Many modifications are contemplated and, to maintain total flexibility, a digital hardware approach is considered the most feasible.

The total computational system envisioned for the ETSS can be considered as consisting of the following:

a. Digital computer where all processing is done.

b. Real-time interface, which provides communication between the digital computer, the simulator, and the student/experimenter stations.

c. The peripheral equipment, which allows the operator to communicate with the digital computer.

1. COMPUTER CONFIGURATION

The ETSS computer complex will consist of the following:

1) One or more central processors.

2) Memory for program and data storage.

3) Input/output channels or processors.

These elements may be organized in many different ways. To indicate the range of possible organization, three fundamentally different configurations are discussed.

1.1 SINGLE-PROCESSOR CONFIGURATION. This configuration would consist of a single central processor and input/output processor. The executive required to enable a single processor to perform simulation and experimentation concurrently would be necessarily large and complex. The executive would have to provide for memory protection, I/O channel allocations, etc. for both functions, as well as the execution of the programs in both functions. This results in a "master" executive controlling the executives required for simulation and time sharing.

An advantage of a single processor would be the flexibility of program and memory assignment. No duplication of routines would be required, as compared to a multiprocessor configuration.

1.2 MULTIPROCESSOR CONFIGURATION. A multiprocessor configuration consists of two or more central processors sharing a common memory bank, as well as its own memory bank. The programs could be structured to allow each CPU to work on programs or routines associated with an experiment and/or simulation. For example, CPU No. 1 could execute all programs required for simulation of the system being simulated while CPU No. 2 could be running time-shared experiments among the experimenter/student stations. At times when both functions, simulation and experimentation, are not being processed concurrently, added capability (such as tactics) could be derived by utilizing the idle CPU for the function currently being performed. In addition, during simulation the memory banks are easily accessible to the experimenter, which gives a real-time capability to the experimenter to monitor the simulator. Also, the experimenter could modify (under certain conditions) portions of the simulation during real-time operation and observe the effect of these modifications.

1.3 MULTICOMPUTER CONFIGURATION. This configuration consists of two separate and independent central processors and separate I/O processors, each working on separate and independent memory units. Such an arrangement allocates a separate computer to the simulation and experimentation process, permits no shared memory, and limits communication from computers to I/O channels. It is obvious that this configuration would allow each of the experiments to be run independently of the others. However, it would only provide a somewhat limited interface between real-time experimentation and simulation.

An additional problem with this configuration would be the inability to utilize the additional core of the other computer for large-scale problems.

This also limits the research application because of the inability to directly access common data blocks except by mass transfer.

1.4 COMPARISON OF CONFIGURATIONS (Table 24, Page M-5). Three possible computer configurations have been described herein. If the facility were to be utilized for off-line analyses of training research, then the single-processor approach would be most desirable. However, the capability of the experimenter or trainee to interact in a real-time environment with the training or simulation being performed is a basic function of the facility. Based upon the computer loading estimate of Para. 2.1, a single processor of the type required would be quite expensive. In addition, the capability to expand is limited to the maximum size that a single processor could be configured, and any additional expansion would entail purchase of a multiprocessor configuration. Another disadvantage of the single processor is that no tasks can be performed if the processor fails. Based on these disadvantages and on the flexibility required of a research facility, a single processor was not deemed acceptable.

A multicomputer configuration limits the on-line research function. In addition, the storage requirements of one computer for a worst-case type experiment would have to be necessarily large, thereby leading to insufficient use of core memory storage for the majority of the simulation and research function. Additional hardware would also be required to support a multicomputer configuration. For these reasons the multicomputer configuration is rejected.

Based upon the above arguments and considering the computer loading estimate of Para. 2.1, the multiprocessor configuration is considered the best configuration based both upon functional requirements and cost consideration. This configuration would provide the flexibility and expandability required of the research facility. In addition, a somewhat limited capability could be procured initially at moderate cost, and expanded to meet the requirements of the facility.

2. COMPUTER PROCESSING

2.1 COMPUTER PROCESSING SPEED AND MEMORY STORAGE REQUIREMENTS.

In order to determine the processing speed and storage required for the computer complex, it is necessary to analyze

24

TABLE 24. COMPARISON OF COMPUTER CONFIGURATIONS

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Single Processor	Programming Ease Flexibility of Program Memory Assignment	All Functions Dependent on 1 Processor No Real-Time Research Capability Complex Executive
Multiprocessor	Permits Real-Time Research and Simulation Permits Some Capability in Case of 1 CPU Failure Executive Less Complex for Facility	Redundant Programs More Difficult to Program
Multi-Computer	Permits Experimentation and Simulation Independently	Limits Research Due to Inaccessibility to Common Data Pool More Hardware Required

the anticipated computer loading for the task. Table 25 (Page M-7) shows an analysis of the computing speed and storage required. In addition, this figure is broken down into the functional requirements for each type of experimentation. The system research function is estimated to require in the range of 200,000 to 300,000 instructions per second and 32,000 to 48,000 words of core memory. These figures are based on the computer requirements of an operational flight trainer (utilizing a Sigma 5) and are in line with computer requirements experience at Link. This will enable the facility to perform high fidelity simulation (without tactics) of a high performance aircraft.

It should be noted that the figures given for the simulation of the system research function are scaled for maximum fidelity - i.e., the figures have been adjusted to allow for the storage and processing of mathematical models that are more detailed and complete than are required for satisfactory simulation. This was done to permit flexibility in the experimental selection of models to enable optimum models for each system to be determined.

The computer speed and storage requirements given for the sensor, training aids, and tactical decision research function are considered to be similar to a common scientific applications time-sharing system. The time required for this time-sharing executive overhead (time sharing only - no simulation) is considered to be in the range of 250 milliseconds per second and the core memory requirement is estimated at approximately 14,000 words. This core estimate is based on current time-sharing systems, an example being the Batch Time Sharing Monitor (BTS) of the XDS Sigma 7 which requires approximately 14,000 words. In order to have sufficient core memory space for the monitor, buffers, and user programs, the XDS BTS system requires a computer size of 48,000 words, and recommends 60,000 words. Table 25 (Page M-7) shows a breakdown of the core memory requirement. In addition, a display processor will be required, and the present PDP-9 could be utilized in this capacity.

Overlay techniques can be used to reduce core memory requirements for data that can be accessed with a tolerable delay. This technique could apply to an index of documents in the video file system. This data (approximately 16,000 words) could be stored in rapid-access devices.

TABLE 25. COMPUTING SPEED AND STORAGE REQUIRED

TYPE FUNCTION	SPEED	STORAGE (WORDS)
. SYSTEMS RESEARCH SIMULATION*	200,000-300,000 inst/sec	32-48K
. OTHER EXPERIMENTS	** 400,000 inst/sec	48K
. Sensor Research		
. Tactical Decision Research		
. Training Aids Research		
(Includes the following)		
Executive (Time Sharing Addition)		4K
Monitor (Basic)		10K
I/O Buffers		2K
Search Prog (Documents)		1K
Tables		1K
User Programs - Data		30K
		48K
Totals	600,000-700,000 inst/sec	80-96K words

* Includes Spare for Expansion
** Included Overhead Time

The computer loading for the complete facility is estimated to be approximately 96,000 words of core storage; these figures include estimates for both the simulation and research function to be performed concurrently. A 20 percent spare capability is included.

As an example of how the number for the systems research function compares with the processor requirements of existing flight simulators, it should be noted that a 707 flight simulator (GP4 Computer) requires approximately 220,000 instructions per second, a 747 flight simulator (Sigma 5 Computer) about 310,000 instructions per second, the F-4E Weapon System Trainer (GP4 Computer) about 400,000 instructions per second, and the F-111A (GP4 Computer) Mission Simulator about 450,000 instructions per second. The latter figures reflect the large amount of tactics simulation that is required for military simulators. For experiments in the systems research function that require an analysis of flight and tactics simultaneously, the added advantages of this shared data pool can be used to the maximum and the system can be reconfigured to enable the simulation function to use the additional core memory of the experimentation processor.

For problems of this nature, a less complicated executive program (which does not provide all the services of the basic monitor) could replace the time-sharing executive mentioned above.

The execution time requirements for the ETSS dictates either a large, fast single computer or a medium size multiprocessor computer. A large, fast single processor was rejected for the reasons cited in Para. 1.4.

Table 26 (Page M-9) represents some typical computer configurations applicable to ETSS requirements. These figures were extracted from Auerbach Computer Characteristics for 1969, and the cost figures are only approximate.

Detailed pricing information on large complexes is difficult to obtain except by extended negotiations with the computer manufacturer, therefore only approximate costs are presented. The processing speeds shown in Table 26 (Page M-9) were obtained by multiplying the computer add time by a factor of 1.3 to obtain approximate average execution time and then taking the reciprocal of this figure to obtain processing speed in instructions per second.

TABLE 26. TYPICAL COMPUTER CONFIGURATIONS FOR THE ETSS

COMPUTER	AVG. INST. SPEED FOR TYPICAL SIMULATOR MIX	INST. PER SECOND	*ESTIMATED SYSTEMS COST
PDP-10	2.46	405,000	700,000
Sigma 5	2.54	393,000	780,000
Sigma 7	1.90	524,000	950,000
IBM 360/44	4.30	232,000	950,000

* Costs include:
2 CPU's (16K memory)
Memory 80K words
2 Tape Drives
Card Reader
Line Printer
1 TTY
High Speed Disc

The scope of this study is such that a single computer manufacturer has not been recommended, but rather a computer capability defined.

3. ADAPTABILITY AND GROWTH CAPABILITY

Because of the broad nature of the research operation and because of the flexibility required for modifying and updating programs, it is essential that the ETSS computer complex have capability for future growth. It must be possible to expand the computer both in processing speed and available memory. The requirement for future expansion dictates that the computer complex be modular in structure so additional processors and memory may be conveniently added.

3.1 DATA WORD SIZE. Many studies have been conducted to investigate word size required for aircraft simulators. These studies have demonstrated that a 16-bit word length is adequate for most simulator data, but that 24-30 binary bits are required to achieve necessary accuracy for certain quantities that are numerically integrated within an integration time frame.

This required accuracy could be achieved by employing a 32-bit word length computer, a 24-bit word length computer that provides double precision computation for the few quantities requiring more than the 24 bits of accuracy, or a 16-bit computer that has double-precision capability for integrated values. The memory penalty generally associated with use of machines with 16- or 24-bit words is negligible. The time penalty is small, particularly if the computer offers double-precision hardware. In general, these disadvantages are more than offset by differences in cost between the small-word-length machine (16- or 24-bit) and the longer-word-length machines (32-26 bit). For economy's sake only, a smaller-word-length machine might be selected. However, in view of varied number of tasks and scope of the simulation problem, a 32- or 36-bit word length computer would best fit ETSS needs.

The need for at least a 32-bit word length computer in the ETSS is substantiated by consideration of the following problems:

a. Addressing Problems - Computer instructions are subdivided into operation code, indexing and indirect addressing bits and address. A machine that utilizes the short word length has few bits for direct addressing and most of the computer memory must be addressed by indirect addressing or indexing. In most cases, this has the effect of increasing execution times of instructions, thereby reducing the speed of the processor. For small simulators this is not an offsetting feature; however, in a real-time multiprocessor system it has a significant effect.

b. Programming Complications - Because of the relatively few bits available for addressing, short word length computers are most difficult to program with respect to referencing.

c. Inefficient Use of Floating-Point Data - Since the facility will undoubtedly use a high-level language such as Fortran, floating-point hardware is a desirable option. Compilers are available for short word length machines but they generate object code that treats data as floating-point numbers. In some instances, object code is run by subroutines on machines that do not have floating-point arithmetic hardware. Such operation, however, poses a time penalty on the program in addition to inefficient use of data words.

Therefore, on the basis of these considerations, the computer used for the ETSS should be one whose word length is at least 32 bits.

3.2 INSTRUCTION REPERTOIRE. The instruction repertoire for the ETSS computer should not be considered unique for the system. Most large computer systems have a full range of instructions which are adaptable to the requirements of such a facility. However, for simulation it is necessary to specify the desirable types of instruction, which are:

a. Fixed-Point Arithmetic Instructions - These instructions should include add, subtract, multiply and divide in both single- and double-precision format. A square root instruction is also very desirable for simulator application.

b. Floating-Point Arithmetic Instructions - As previously mentioned, a hardware floating-point capability is required for efficient utilization of a high-level language compiler. Floating-point operations should include at least add, subtract, multiply and divide instructions. A floating-point square root instruction is also desirable.

c. Logical Instructions - This set should contain unconditional branch, conditional branch, compare and branch, and branch and store instructions. In addition, the conditional branch instructions should provide for several conditions such as branch if a number is positive, branch if a number is negative and branch if a number is zero. The compare and branch instruction should provide for comparison of two numbers with appropriate branches taken depending on the result of comparison.

d. Boolean Instructions - This should include AND, OR and Exclusive OR instructions. It is desirable that Boolean instructions operate upon single bits instead of full words and, therefore, bit addressing at least between registers is a very desirable capability. Because of the large number of Boolean operations inherent in simulation, the capability of performing bit addressing between registers and memory is also very desirable because it will permit all Boolean data to be packed into full words for storage in the computer. This capability would enhance handling of discrete outputs.

e. Data Handling Instructions - A set of instructions must be provided that would enable the computer to transfer data between memory and CPU registers and also to input and output data through I/O channels. These should include single- and double-precision load and store instructions, shift instructions, including double-word shifts and I/O block transfer with the block length selectable. If the computer has a word length of 32 bits or greater, data handling instructions should permit utilization of halfwords and bytes as well as whole words.

4. PERIPHERAL EQUIPMENT

Several types of peripheral equipment are required for the ETSS facility (See Table 27, Page M-13).

a. Operator Control - A teletypewriter is considered to be the primary device for exercising control during simulation and/or experimentation. This enables the operator to communicate with the computer through such programs as utility programs.

b. Program Loading - Because of the flexible nature of the ETSS, a means must be provided to permit rapid loading and modification of various types of experiments and simulation.

TABLE 27. PERIPHERAL EQUIPMENT REQUIRED FOR THE ETSS

PERIPHERAL	QUANTITY	FUNCTION
Card Reader	1	. Program Loading
High Speed Printer	1	. Printouts, Dumps, Diagnostics, etc.
CRT Terminals	8	. Experiments
High-Speed Disc or Drum	1	. Provide for Efficient Time Sharing . Rapid Data Access . Performance Recording
Low-Speed Disc	1	. Program Storage . Data Storage . System Software Storage (Utilities)
Magnetic Tape Units	2	. Rapid Program Loading . Permanent Data Recording . System Dumps
Teletype	1	. Control/Communication
Console	1	. Control

Programs are usually stored in hard form on cards and, having passed an appropriate loader, assembler or compiler, are then made available to the computer through a rapid loading device such as magnetic tape, disc, or drum.

c. Program Modification - Because of the inherent need of the ETSS facility to be able to update and modify programs as they are being researched, the facility has a need for terminal/experimenter stations in a time-sharing mode. As presently envisioned, the facility will have at least eight time-sharing terminals of the CRT type to enable the experimenter and subjects to communicate with each other and the computer. To enable the facility to offer a flexible time-sharing system during an experiment,a high-speed, rapid-access device such as a high-speed disc or drum must be available.

d. Data Recording - In addition to time-sharing, the ETSS must have capability of recording performance data in a real-time mode and being able to analyze data both in a real-time and off-line mode. To do this requires a disc or drum to enable the experimenter to store data as it is being generated and recall it at a high access speed. In order to do this without sacrificing core memory storage, it is recommended that sufficient disc space or drum space be available. In addition, some recording of data might be desired to be retained on magnetic tape for more permanent storage.

e. Hard Copy Output - The system must have capability to provide hard copy output for dumps, listings, results, etc. To provide this, a high-speed printer is recommended.

f. Alphanumeric CRT Terminals - The CRT terminals will be used for monitoring and control. A display subsystem should be used such that one interface is utilized between the computer and the CRT subsystem. All multiplexing and refreshing will be accomplished within the CRT subsystem (an example of this system is the Data Disc 6500 graphic system).

5. COMPUTER SIMULATOR INTERFACE

In order to effectively transfer information between the digital environment of the computer and the analog environment of the simulator, interface equipment is required. The computer interface equipment must be bidirectional - that is, it must transfer data into, as well as out of, the computer. During ETSS operation, the computer interface equipment will perform three major functions:

a. Accept time-multiplexed (sequential) output from the computer, generally byte-serial or word serial and transmitted on a single set of data lines. The computer interface equipment, in order to properly accept these outputs, must incorporate a controller with counters, logic and gating for steering each output word (or byte) to its correct destination.

b. Convert each output into the form best suited to its ultimate use. The conversion may be as simple as changing voltage levels or current drive capability or it may involve digital-to-anlog conversion.

c. Store the outputs in parallel fashion to provide continuous (nonmultiplex) outputs on separate lines. This storage may take the form of flipflops for discrete digital outputs or sample-and-hold amplifiers for analog outputs.

For input operations the computer interface equipment will perform three similar, but slightly different, functions:

a. Periodically sample continuously available inputs (digital or analog) that are provided on separate lines.

b. Convert each input to digital form at levels suitable for transfer to the computer.

c. Transmit the input data to the computer in byte-serial or word-serial (time-multiplexed) fashion.

For inputs as well as outputs, the computer interface equipment controller must provide the necessary bookkeeping to insure that data are properly routed.

5.1 **INTERFACE ON THE COMPUTER SIDE.** As mentioned previously, the computer side of the interface operates in a time-multiplexed, or serial mode. A considerable number of types of computer I/O channels are available. The nature of the I/O channel is one of the important parameters affecting the nature of the performance of the computer interface equipment.

Computer I/O channels generally form one of two major classifications: single-word channels and block transfer channels. The single-word channels are unsuitable for applications such as ETSS, which requires the exchange of large amounts of information between the computer and interface equipment. These channels require execution of an I/O instruction by the CPU for every word transferred. These instructions, plus the bookkeeping instructions necessary to establish block limits and timing, impose an undue burden on the CPU.

Block transfer channels have the capability of automatically transferring large blocks of data after being initiated by a single set of instructions. The block transfer type of I/O channel is essential to the ETSS in order to minimize I/O system demand on processor time. This is especially true when simulation and experimentation are being preferred simultaneously.

Specific implementation of block transfer I/O channels varies considerably, but major characteristics of most such channels can be defined in terms of four parameters:

a. Cycle-Stealing - A block transfer channel may or may not be a cycle stealer. A cycle-stealing channel is one that interrupts a CPU for a short period of time (generally one memory cycle) for each information transfer. This usually results from the sharing of registers, arithmetic capabilities or a common memory bus. Non-cycle-stealing channels are generally more expensive than cycle-stealing types but, because they possess their own registers, control logic and memory ports are able to access memory in an overlapped fashion to minimize CPU time penalties when several memory blocks are involved. A non-cycle-stealing I/O channel is desirable for the ETSS to minimize CPU delays.

b. Word or Byte Orientation - Some block transfer channels are word-oriented; that is, a full word is transferred in parallel to or from the computer interface equipment. Other channels are byte-serial in that each word is subdivided into two or more bytes that are transmitted serially to or from the computer interface equipment. Often the byte-serial I/O channel is further limited in that only one byte is obtained from or stored in memory with every access. In such cases the memory access requirements are increased and the data rates are decreased compared with channels that provide word assembly/disassembly in the I/O channel. For the ETSS, a word-oriented channel is desirable since the control logic in the computer interface equipment is simplified. The improved flow rates may or may not be of significance, depending on whether the actual data rates obtained with specific channels meet the specific requirements of the ETSS.

c. Multiplexing - Some block transfer channels are multiplexed so they can service two or more devices on an interlaced basis according to some priority scheme. Such channels usually incorporate separate range and address counters for each device interface. Each time access to core memory is obtained, a word (or byte) of information is transferred to or from the highest-priority device requesting access, and the appropriate range and address counters are modified. Non-multiplexed channels are able to service only one device at a time. Once a block transfer is initiated, all other devices are locked out until an entire block of words has been transferred. A multiplexed I/O channel is generally desirable for servicing devices that are slow in comparison to the I/O channel data rates, whereas a non-multiplexed channel is adequate for devices that can operate at a rate approaching the I/O channel rate. Since the computer interface equipment will incorporate analog-to-digital and digital-to-analog converters, which are relatively slow, the multiplexed type of I/O channel is desirable.

d. Buffering - Some block transfer channels are buffered to minimize timing problems. When a channel is not buffered, the device must generally respond to a core memory access within a specified time frame. In other words, this interface is synchronous. A buffered channel, on the other hand, provides an asynchronous interface in that the core memory and its devices operate in their own time frame, while a buffer register provides storage from the time the data is available until the time it is used. Whether or not a buffered channel depends on I/O timing and the distance of the device from the computer, as well as other less important factors. Generally for servicing computer interface equipment, a buffered channel is desirable but not essential.

5.2 INTERFACE ON THE SIMULATOR SIDE. The simulator side of the computer interface equipment consists of a large number of parallel input-output channels, each of which is suitable for its intended purpose. In general, the outputs assume steady-state values that are updated periodically by the computer. Some form of storage is required to maintain the values between updates. Inputs, on the other hand, are maintained and are sampled periodically by the computer equipment for transmission to the computer. The most common types of I/O channels are:

a. Discrete Inputs - These are generally obtained from switches, encoders, or other devices that are essentially discrete or digital in nature. Individual discrete signals or individual bits in digital words are generally grouped into words for transmission to the computer.

b. Discrete Outputs - These are signals used to drive lights, relays and similar devices external to the computer. From the standpoint of interface equipment complexity and data rates, it is desirable to group these outputs in the same way that the discrete inputs are grouped. But since packing of the outputs by the computer may impose a severe time penalty, they are often output in the same form generated by the computer.

c. Analog Inputs - These are DC analog voltages, usually in the -10 volt to +10 volt range, which are sampled periodically and converted to digital form by an analog-to-digital converter for transmission to the computer.

d. Analog Outputs - These are DC analog voltages, usually in a range of -10 volts to +10 volts, which are updated periodically by a digital-to-analog converter that receives inputs from the computer. One technique employs sample-and-hold amplifiers, which provide storage of the analog voltage between updates.

e. Synchro/Resolver Outputs - These are AC analog voltages, most often 400 Hz, which are used to drive synchros and/or resolvers. These are often driven by DC analog outputs. Direct digital-to-synchro converters are also available. The selection is most often based on comparative costs since both provide adequate performance.

Division of the computer interface equipment into four or five types of I/O channels as described is almost universal, since all simulators require a variety of types of I/O. The ETSS can be expected to require all of these types of I/O channels. The special nature of the ETSS, however, dictates a further division of the problem. This derives from the fact that the ETSS is a multi-function facility. When using a single computer complex with a single processor or multiprocessor to drive two or more functions, a decision must be made as to whether a single computer interface system should be used to drive the experiments and simulator or a separate computer interface should be used for the experiments and the simulator. The main arguments favoring a single interface system are:

a. Flexibility - Where a single interface system is used to handle both functions, all spare inputs and outputs are available for assignment to any of the other functions. This provides somewhat more flexibility than a situation in which each function has its own interface equipment including spares.

b. Cost - A single interface system with a single controller is inherently less expensive than two separate interface systems.

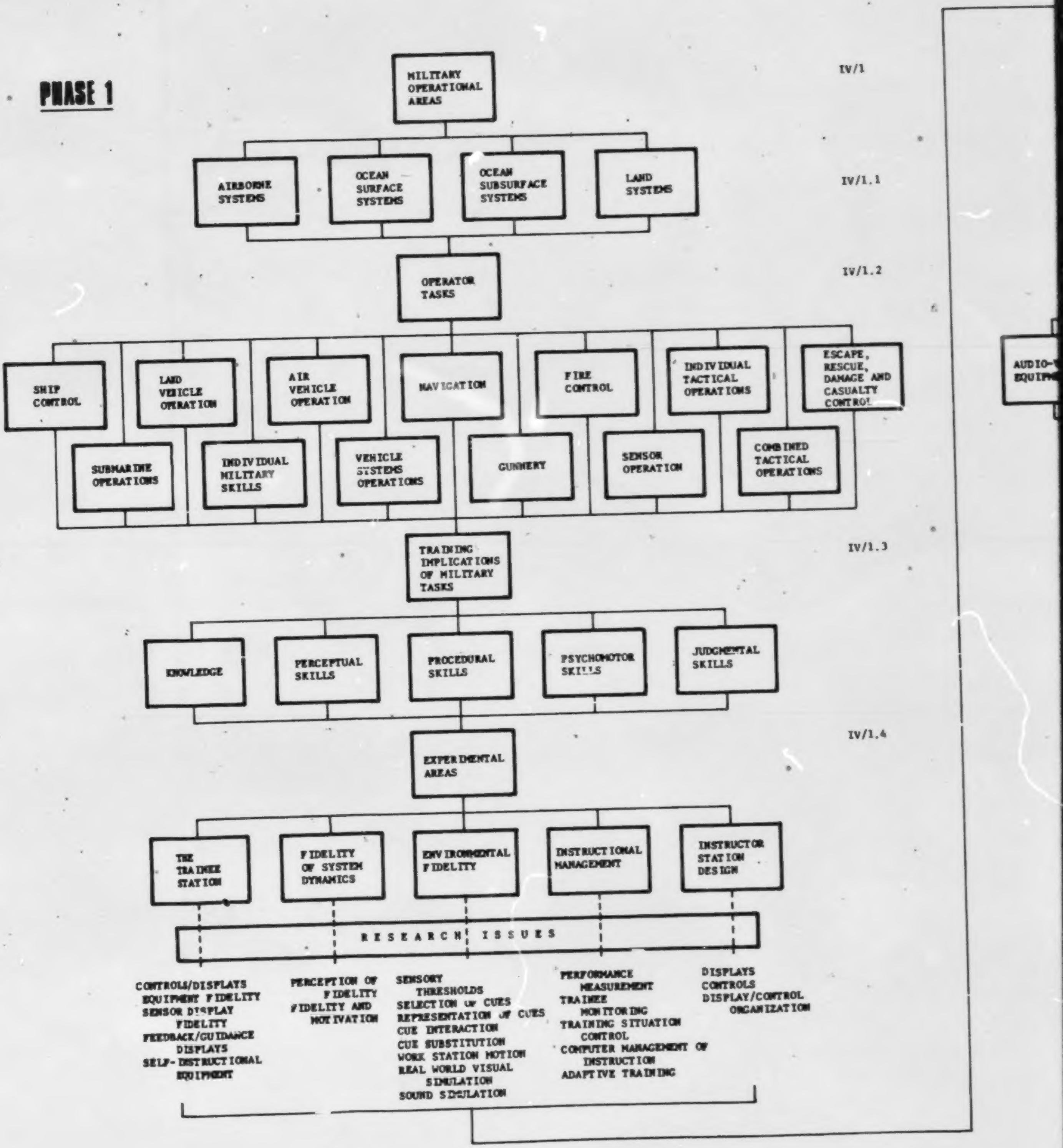
On the other hand, arguments favoring the use of the separate interface systems are:

a. Availability - When a single interface system is used for both functions, a failure in a crucial area, such as the controller, or the maintenance procedures for a failure in a less critical area may necessitate shutdown of both functions. On the other hand, if such interface systems are independent of the others, a failure of one has no effect on the others and training and/or experimentation can proceed at a reduced level.

b. Data Rates - In general, the use of separate computer interface systems coupled with a multiplexer I/O channel can significantly improve the data rates over those that can be achieved at a single computer interface.

It is therefore recommended that two separate interfaces be utilized.

Section/Para.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OCEAN SUBSURFACE SYSTEMS
LAND SYSTEMS
IV/1.1
OPERATOR TASKS
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NAVIGATION
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ESCAPE, RESCUE, DAMAGE AND CASUALTY CONTROL
AUDIO-V EQUIPM
SUBMARINE OPERATIONS
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FEEDBACK/GUIDANCE DISPLAYS
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CUE INTERACTION
CUE SUBSTITUTION
WORK STATION MOTION
REAL WORLD VISUAL SIMULATION
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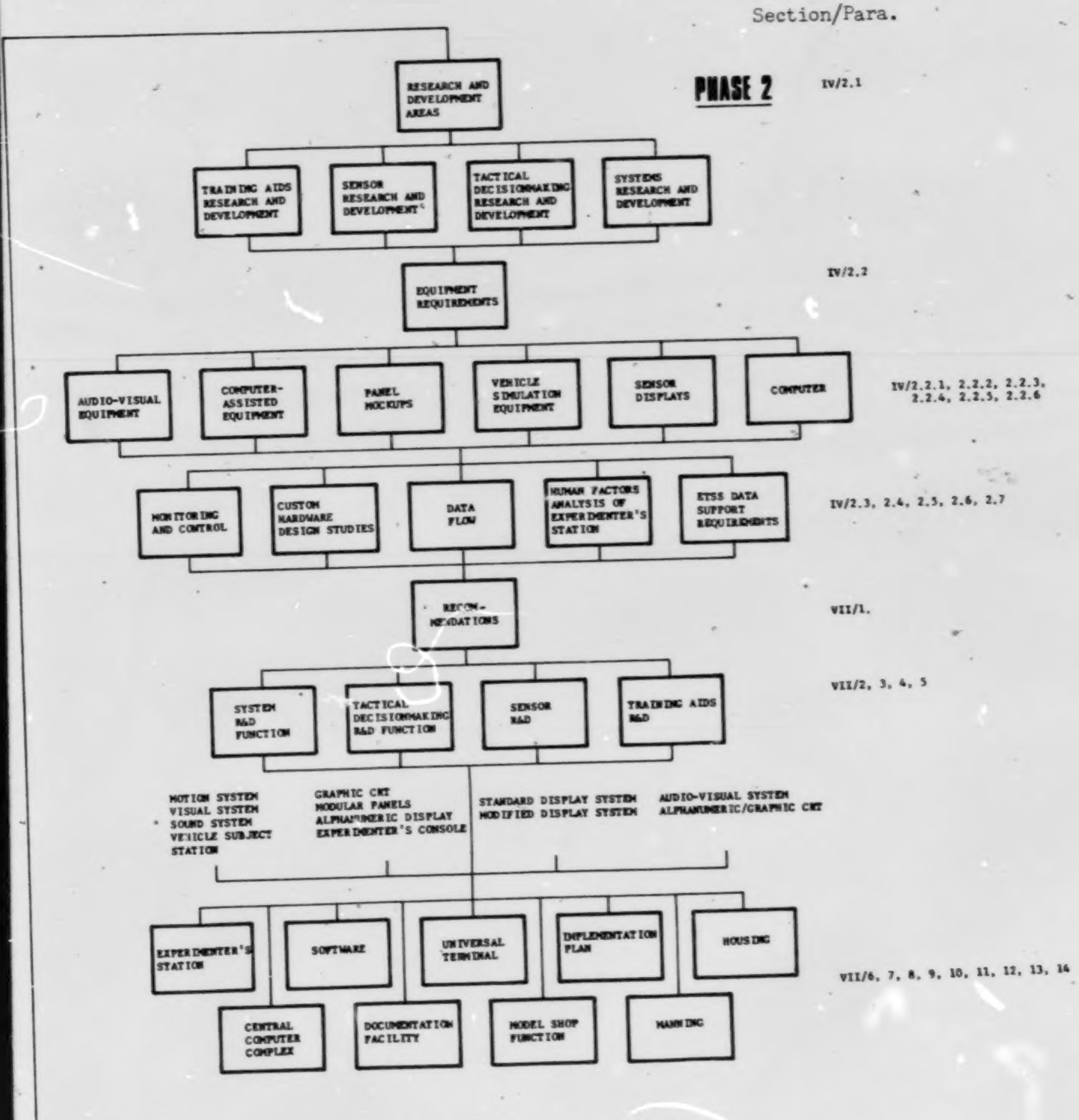
PERFORMANCE MEASUREMENT
TRAINEE MONITORING
TRAINING SITUATION CONTROL
COMPUTER MANAGEMENT OF INSTRUCTION
ADAPTIVE TRAINING
DISPLAYS
CONTROLS
DISPLAY/CONTROL ORGANIZATION


Section/Para.
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ALPHANUMERIC DISPLAY
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DOCUMENTATION FACILITY
MODEL SHOP FUNCTION
MANNING

Figure 44. ETSS Study Overview

DOCUMENT CONTROL DATA - R & D

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13. ABSTRACT

A study was performed to define an experimental system for the solution of human factors problems in training device design. Phase I identified training design problem areas through a review of tasks performed in military systems, and of the training implications of these tasks. Phase II identified equipment and software capable of supporting relevant experiments.

Recommendations are made for an Experimental Training Simulation System for experimentation in (1) the design of trainee stations, (2) system fidelity requirements, (3) environmental simulation fidelity, (4) automated training, and (5) instructor station design. A five-year implementation plan is presented, for the procurement of modules to be employed independently, and in conjunction with each other as they are procured.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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